

JET PROPULSION

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AMERICAN ROCKET SOCIETY

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The 350,000-Pound Thrust Rocket Test Stand at Lake Denmark, N. J.	
. B. N. Abramson, D. S. Brandwein, and H. C. Menes	291
An Air-Transportable Liquid Oxygen Generator—Its Operation and Application	
. G. A. Bleye, R. B. Hinckley, and C. L. Jewett	297
A New Supply System for Satellite Orbits—Part 1	
. Krafft A. Ehrcke	302
Unconditional Stability of Low-Frequency Oscillation in Liquid Rockets.	
. Sin-I Cheng	310
The Crucial Problem in Astronautics: Recovery of Multistage Vehicles	
. G. A. Crocco	313
Technical Notes	316
Kaeppler, on Cooling of Nuclear Rockets	
Summerfield, Foster, and Swan, on Flow Separation in Supersonic Nozzles	
Thomas, on Countermeasures for Satellite Vehicles	
Cash, on Recovery of Propulsion Systems	
Sterling, on Radio Communication in Space	
Jet Propulsion News.	325
ARS News	333
Book Reviews	337
Technical Literature Digest	341

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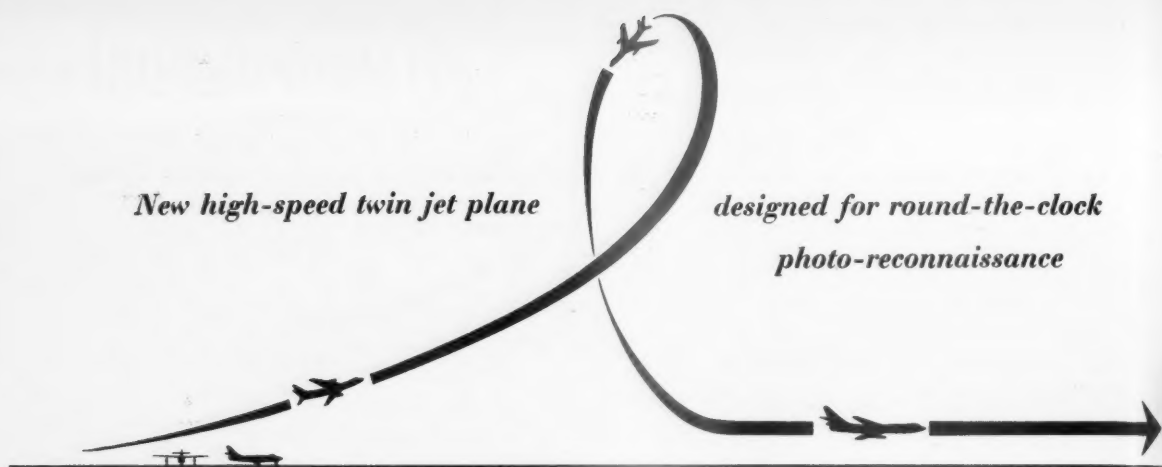
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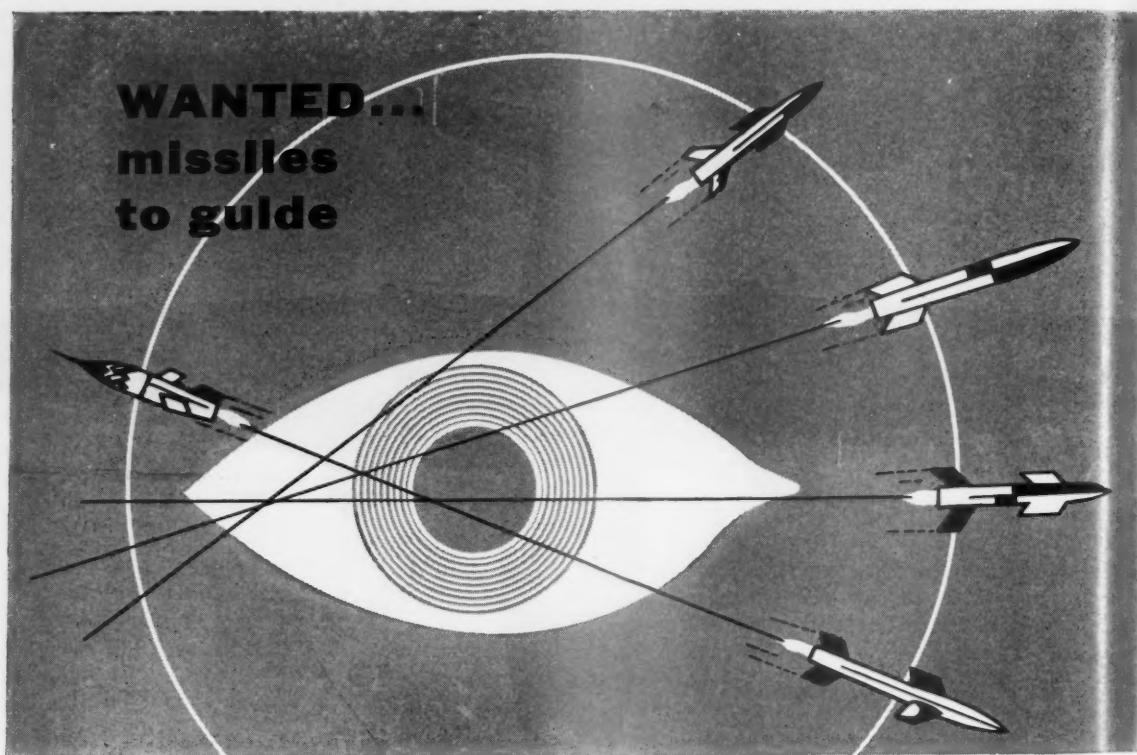
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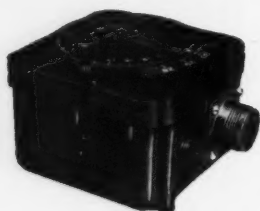


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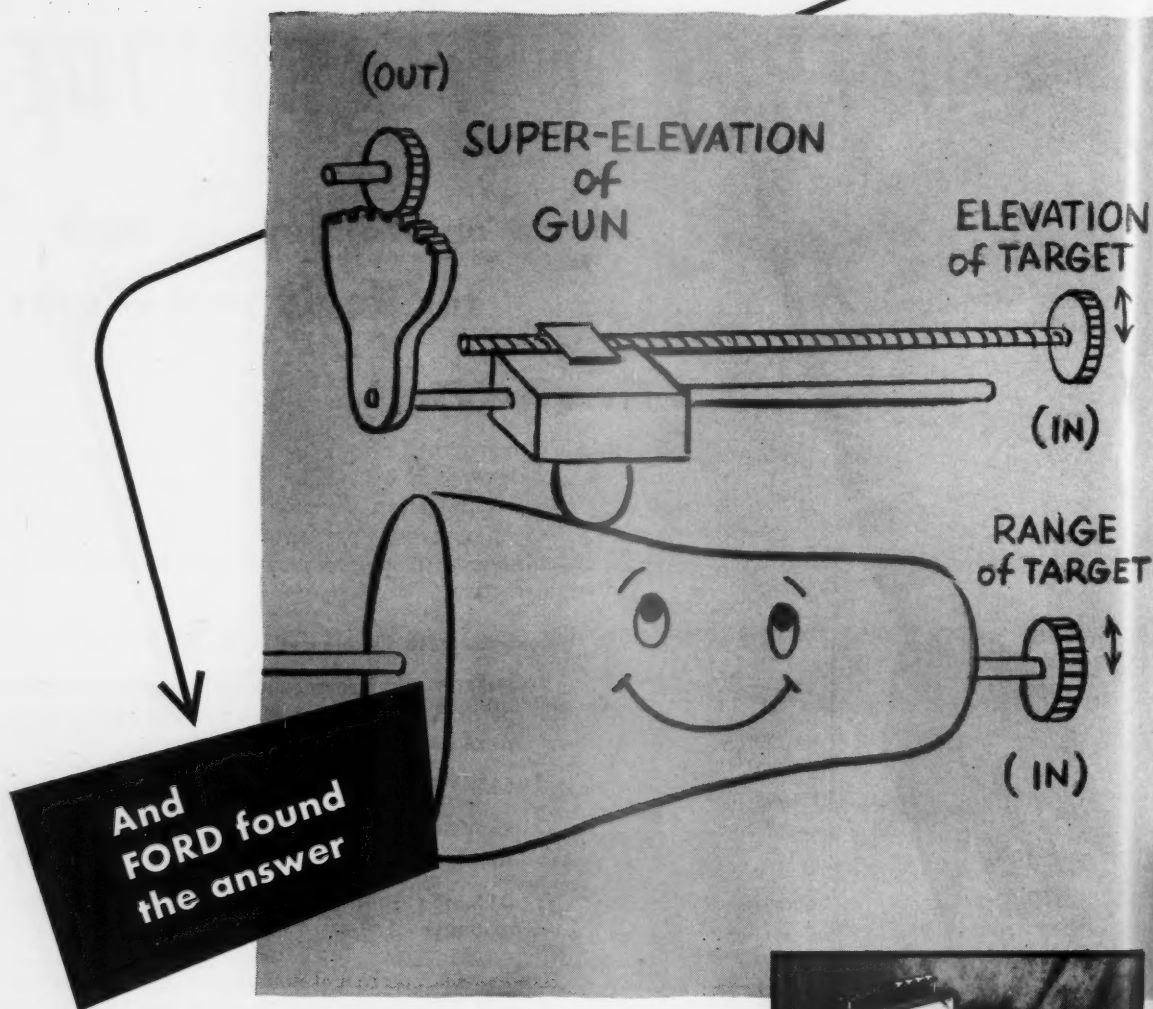
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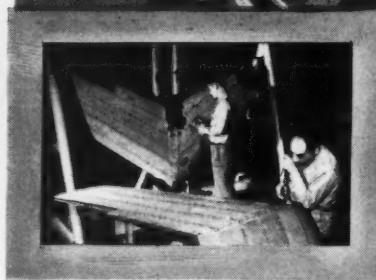
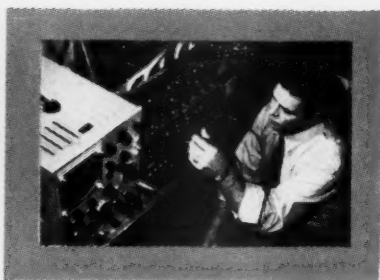
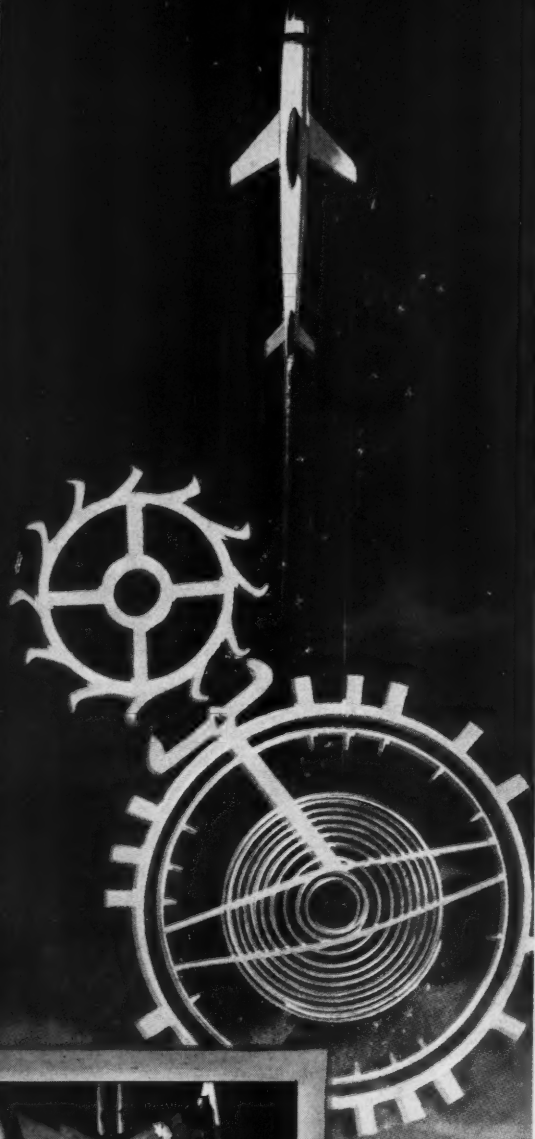
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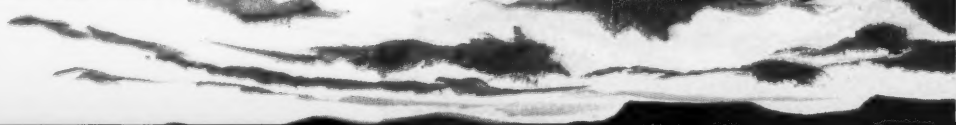


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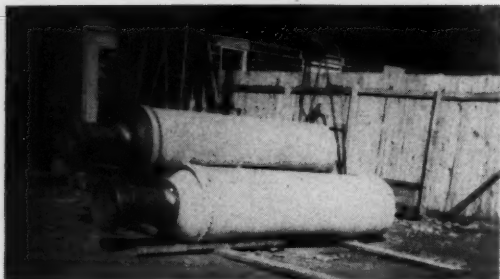
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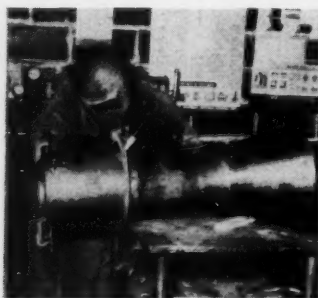
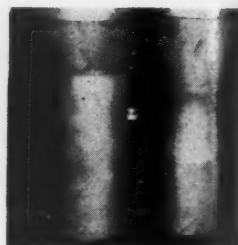
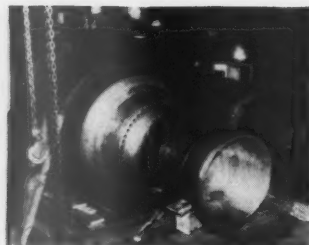
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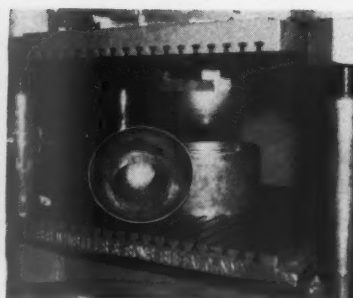
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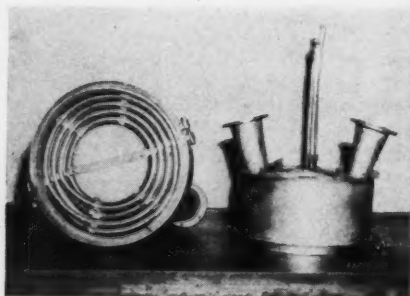
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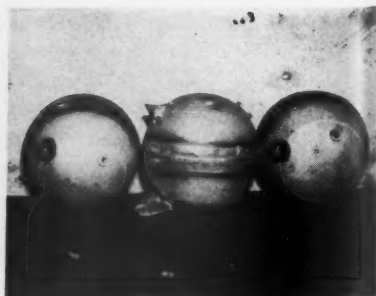
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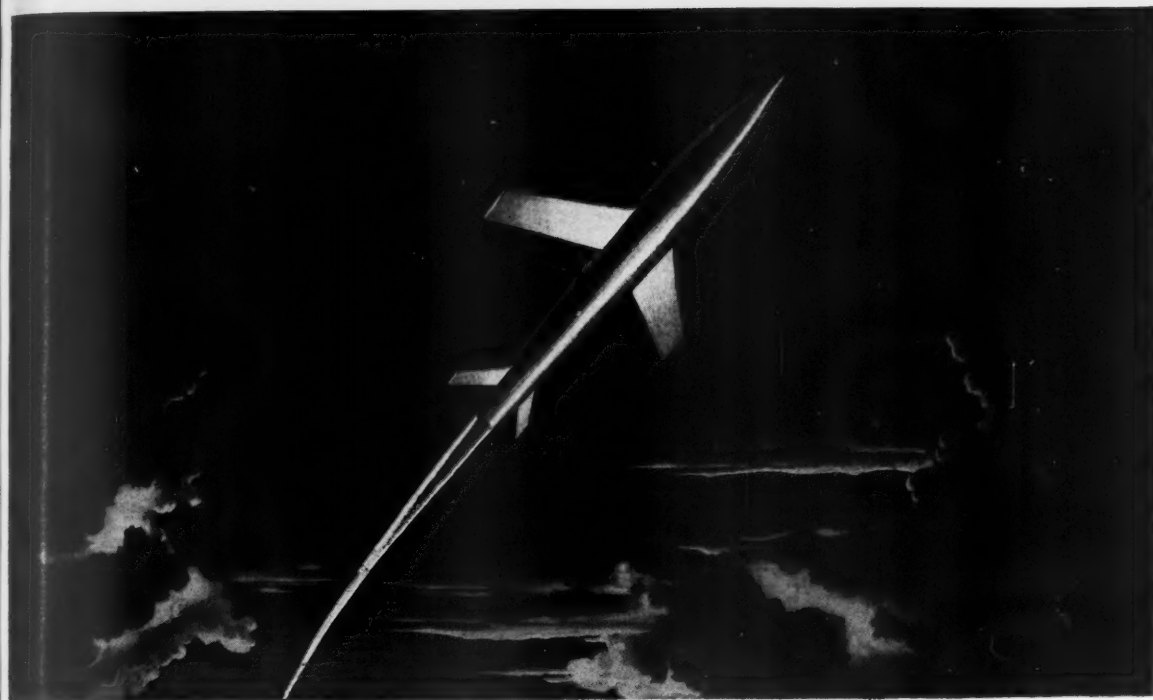
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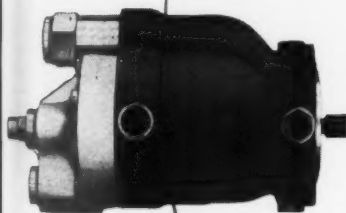
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The 350,000-Pound Thrust Rocket Test Stand at Lake Denmark, N. J.

B. N. ABRAMSON,¹ D. S. BRANDWEIN,² and H. C. MENES³

U. S. Naval Air Rocket Test Station, Lake Denmark, Dover, N. J.

A 350,000-lb thrust static test stand has been constructed at the Naval Air Rocket Test Station for the testing of rocket engines or rocket powered missiles.

The stand is constructed of steel and concrete. The basic structure is a steel cantilever. Thrust loads are applied 7 ft, 6 in. from the fixed end of the cantilever. Control of operations is effected from the underground level in a blockhouse 250 ft distant. Workshop space is provided in the blockhouse on ground level. Firing attitude range is from vertical to horizontal. By means of an inclined ramp, truck access directly to the firing mount is provided for missiles up to 90 ft long. The vertical distance from the firing mount to the ground is 60 ft. Water for cooling the exhaust jet is available. The stand has separate cascade rooms for individual pressurization of propellants.

1 Introduction

IN EARLY 1950, studies of existing rocket test facilities indicated the need for additional large-scale thrust stands. The construction of individual facilities for specialized tasks was studied with the conclusion that the cost of such construction would be prohibitive. In line with current trends, therefore, it was decided that a single universal facility, centrally located, on a government reservation, would meet the needs of the Bureau of Aeronautics and probably those of other departments of the Military Establishment.

The thrust rating of the stand was selected at 350,000 lb. The stand was to incorporate space for a variety of propellants and propellant feed systems of one-minute duration at the maximum thrust level. Provisions were to be made in the design to allow for expansion of the feed systems. To increase its utility, the test facility was to permit static firing of missiles in addition to basic engine firings.

The location of the stand, in the Middle Atlantic area, has the advantage of proximity to large manufacturing centers and to several important firms engaged in rocket engine and missile development.

2 Basis of Design

One of the most difficult problems in the design of a large static thrust stand is that of exhaust flame disposal. Since

most large rocket engines are fired vertically downward during their development, the problem becomes one of providing protection from the effects of the exhaust jet energy. This was done by selecting a site on the steepest hill on the Government reservation. From inspection of existing large thrust stands, it was decided that the distance from the nozzle exit to the first point of impingement on the ground should be a minimum of 50 ft. Experiments by the Naval Air Rocket Test Station made in 1951 showed that a rocket exhaust flame could be nearly quenched by injection of moderate amounts of water into the core of the flame. As an additional safeguard, water headers were to be incorporated in the design to permit the injection of water just downstream of the rocket engine nozzle.

The slope of the site selected still did not permit a minimum of 50 ft clear distance, so a cantilevered design was chosen to provide the required additional distance. The requirements that the stand permit attitude firings of missiles from vertical to horizontal was also met by the cantilever arrangement. It was thought desirable to permit assembly and repair work on a missile in the horizontal position, thereby obviating a system of platforms and ladders such as is commonly found on fixed vertical stands. The stand now began to take the form of a long working area with the pivot point of the thrust mount cantilevered out from the supporting substructure.

The propellant feed system was to incorporate a bipropellant tank system, pressure or pump-fed. Once again the terrain dictated an arrangement of tank and cascade rooms under the working area of the stand. The room size was determined and a layout made which resulted in separate tank rooms and separate cascade rooms for the fuel and oxidizer, all susceptible to future expansion.

For safety reasons, consistent with previous experience, the control room was to be a separate structure, 250 ft from the stand, and placed underground. All test-firing operations were to be controlled from this room. On the grade level of this building, a field maintenance shop would provide an assembly area for components. Personnel service areas, such as offices, sanitary facilities, and locker space were also to be included.

Consideration of climatic conditions the year round dictated a shelter over the working area. Light construction was to be used, due to the possibility of an explosion. The tank and cascade rooms were to receive the same type of weather protection for ease of venting explosions and economy of replacement.

A system of roads was laid out which would permit direct truck access between all areas requiring transport of heavy equipment. Both tank rooms have parking areas adjacent to them for tank truck loading of propellants.

Presented at the Eighth Annual Meeting of the AMERICAN ROCKET SOCIETY, New York, N. Y., December 2, 1953.

¹ Head, Power Plants Division.

² Head, Test Branch.

³ Head, Instrument Branch.

After a review of the above and other minor requirements, a complete set of specifications was drawn up by the Rocket Station which spelled out area and room sizes, loads, safety factors, utilities, and process details. Specifications for instrumentation, other than space and conduit requirements, were deliberately omitted since it was the intention that the complete instrumentation system would be handled by Station personnel. This set of specifications and a preliminary layout of the structures formed the basis for the design.

3 Preliminary Design

The preliminary layout of the test stand is shown in Fig. 1. The structure is reinforced concrete, with the thrust load taken through steel members anchored to bed rock. Fig. 2 shows the vertical members being erected.

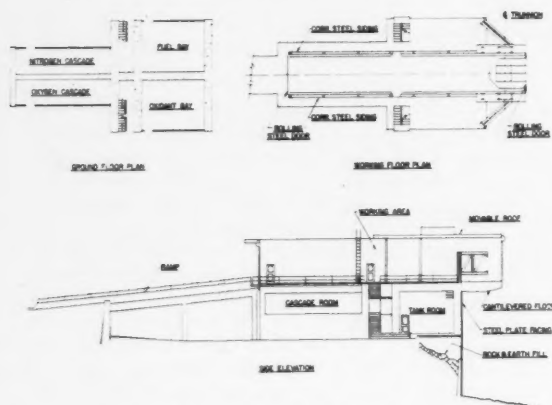


Fig. 1 Test stand layouts

The test stand structure is built in three levels: a basement, ground floor, and working floor. The ground floor contains the two propellant tank rooms and the two cascade rooms. The outside wall of each of the four rooms is fabricated of corrugated metal siding on light steel framing. In addition, a

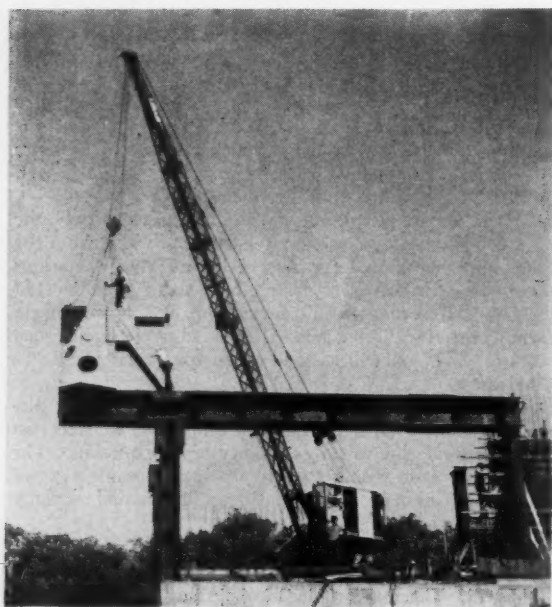


Fig. 2 Main steel skeleton

reinforced concrete barricade 8 ft high runs parallel to the outside face of the cascade rooms to protect personnel outside from gas pressure explosions.

The working level is one room, 94 ft-0 in. by 15 ft-10 in. by 17 ft-6 in. high. The thrust pivot point is 7 ft-6 in. from the face of the substructure. The roof of this room is movable and can slide back 50 ft from the end of the cantilever, thus permitting erection of a missile tank section to the vertical. The dimensions of the cantilevered floor are 15 ft-0 in. by 15 ft-0 in. This floor is provided with bomb bay doors beneath the rocket centerline. To insure that the trunnion mounting will accommodate large propulsion units, the trunnions are placed 12 ft-6 in. apart.

The thrust structure was designed to carry a normal load of 350,000 lb and a side load of 40,000 lb under steady-state conditions. As a safety in the event of an explosion, the design loads were multiplied by a factor of 3, and the steel work was then stressed to a maximum of 20,000 psi.

After a careful review of the economy versus accessibility, a direct ascent of the slope was decided upon. This resulted in an access road of 1400 ft in length with a maximum grade of 14.9%. Fig. 3 shows the layout of roads and the areas serviced.

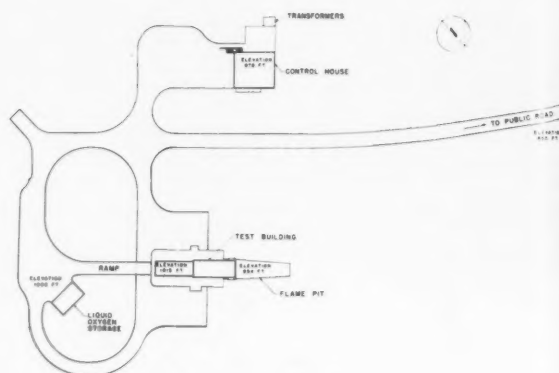


Fig. 3 Site plan

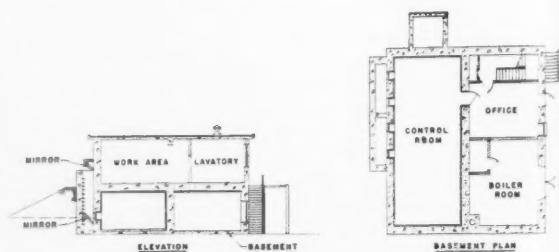


Fig. 4 Control house layouts

The layout of the upper and lower floors of the control house is shown in Fig. 4. The control room proper contains the firing console and all recording instrumentation. Instrument signal cables are run underground from this room to the test stand termination room through hollow clay tile ducts in the general utility trench. Viewing is accomplished by a periscope arrangement of mirrors in a concrete areaway.

Since the first use of this stand is the development of an engine with a thrust less than the maximum rating of the stand, operating on the combination of anhydrous ammonia-liquid oxygen, a number of specific components in the installation were tailored to meet this use. The entire propellant feed system, discussed in the following section, was built for this engine. The engine mount and operating floor were designed around this engine.

The engine mount is basically a hollow beam of rectangular cross section bridging the space between the trunnions. The engine is attached to the beam through three load cells spaced at 120 deg, thereby allowing measurement of eccentric thrust. The mount can be rotated about the trunnion centerline through an arc of 90 deg by means of a sector plate and locking pin on one end. Design loads and stresses had the same basis as the trunnions, that is, an overload factor of 3 and a maximum allowable stress of 20,000 psi. The completed mount was loaded with a hydraulic jack in an orientation which was the resultant of the axial and side loads. Strain gages showed the maximum stress in the steel to be 3300 psi. Unavailability of certain sizes of steel plate necessitated the use of heavier material which accounted for the overdesign. Fig. 5 shows the mount in place.



Fig. 5 Cantilevered firing balcony

The operating floor under the mount contains two sets of double doors hinged parallel to the centerline of the stand, either or both to be opened immediately before test firings. The doors are remotely actuated by an electric motor drive. Fig. 5 shows the doors in the open position.

On the front face of the stand are two 8-in. raw water feeders to supply jet cooling water to nozzles which will be immersed in the flame. These feeders can be seen in Fig. 5.

The principal load carrying steel members are: four 24 WF 94-lb beams in vertical tension, two 24 WF 100-lb beams in vertical compression, and four 36 WF 300-lb horizontal beams. The trunnions are 13 in. in diameter and extend 15 in. from the face of the support.

Concrete walls vary from 18 in. to 3 ft in thickness. The concrete ramp leading to the working floor is an independent structure on concrete abutments.

4 Process Details

The process piping was designed primarily around the first use of the stand. Funds were not available to make the process piping "universal." The selection of sizes, materials, and methods of construction was made on an economic basis.

Propellants are fed to the engine by a pumped system, using the pumps designed for the engine by the development contractor. Consequently, tank pressure requirements were for suppression of cavitation and losses to the pump inlets only.

The propellant tanks were sized for one 2-min run at rated thrust. The 3000-gal ammonia tank is made of low-carbon steel, is rated at 225-psi working pressure, and is constructed according to the ASME Code for unfired pressure vessels. An available 2500-gal, stainless steel tank, rated at 50-psi working pressure, is used for liquid oxygen.

In addition to the propellant tanks, a cooling water tank of 2400-gal capacity is located in the fuel tank room. This is used as the source of engine jacket cooling water. The tank is rated at 1500-psi working pressure, according to ASME Code construction, and is made of low-carbon steel. Because of its size and pressure rating, it was most economical to make the tank spherical, with a wall thickness of 2 3/4 in. Fig. 6 shows the fuel and water tanks.

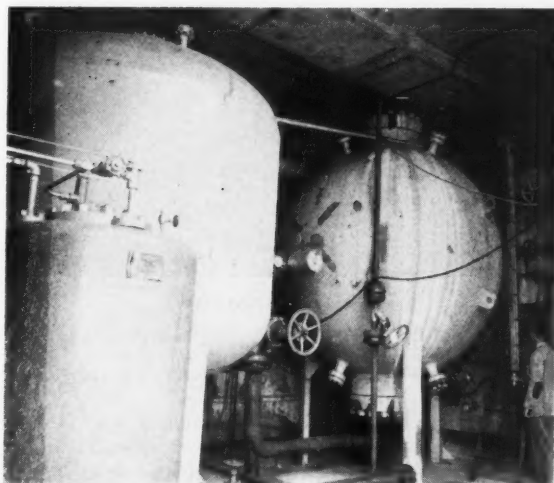


Fig. 6 Fuel and cooling water tanks

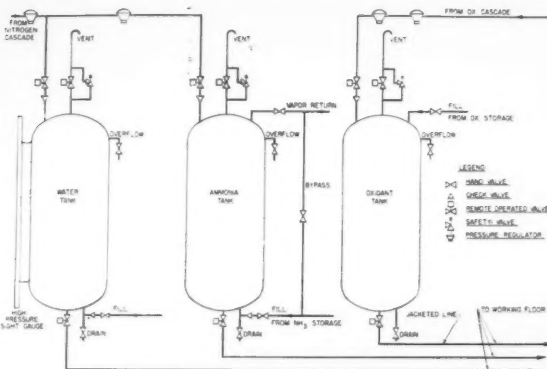


Fig. 7 Process firing schematic

The basic process piping schematic is shown in Fig. 7. Propellants are pressurized by gas, stored at 2000-2200 psi, reduced to proper values by remotely controlled regulators, and piped to the tops of the liquid tanks. The liquid outlets are piped directly to the working floor. Fill, vent, and overflow lines are provided. All valves used in firings are remotely operated.

Nitrogen gas, for pressurizing fuel and cooling water, is stored in a cascade of 80 high-pressure bottles, arranged in four banks. This arrangement was dictated by the availability of the bottles from surplus. Each bottle has a 6-cu-ft water volume and is of multilayer construction. The bottles have a Navy pressure rating of 3000 psi, using a factor of safety of 2.1 based on yield stress. Fig. 8 shows the nitrogen cascade.

Gaseous oxygen is used to pressurize the liquid oxygen. This was done to prevent dilution of the liquid oxygen by pressurizing nitrogen gas. The gaseous oxygen cascade consists of two boxes containing 25 bottles each, with a total water volume of 406 cu ft. These boxes were obtained from

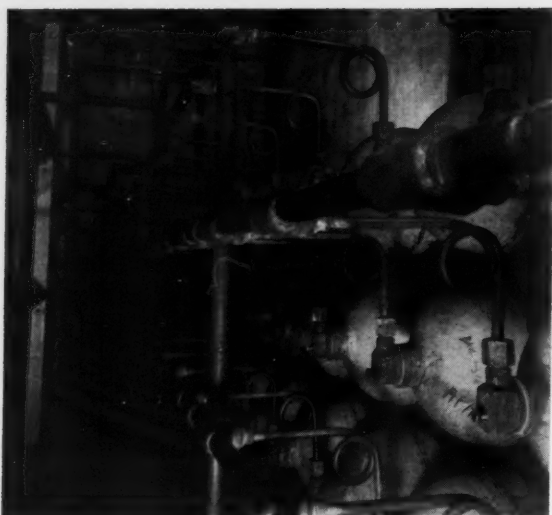


Fig. 8 Nitrogen cascade

the Charleston, S. C., Navy Yard, where they were in oxygen service. Fig. 9 shows the oxygen cascade.

The liquid ammonia line is welded, flanged, carbon-steel pipe. The liquid oxygen line is hard-drawn copper, Type L or K with silver soldered joints. The gas piping is largely brass pipe with silver solder socket fittings. The small diameter piping for pneumatic controls is flared tubing, aluminum or stainless steel, with AN fittings. Because of the intermittent nature of the use of the stand, no insulation is used on the liquid oxygen system, except for the 6-in. outlet line from the liquid oxygen tank to the working floor. This section of line is insulated by a jacket connected to a vacuum pump. This is done to minimize boiling of liquid oxygen being pumped from the tank to the engine.

Liquid oxygen is delivered by the vendor's truck to a 10,000-gal jacketed storage tank 180 ft from the tank room. It is gravity fed from there to the propellant tank through a 3-in. brass pipe. In addition, the feed will be pressurized to 5



Fig. 9 Oxygen cascade

psi by evaporating liquid oxygen from a coil exposed to outside air.

Ammonia is loaded into the propellant tank by making use of an existing 13,000-gal ammonia storage tank at the foot of the hill upon which the stand is located. Two pipelines connect the tanks: a liquid line, and a vapor return line. A compressor at the storage tank pumps vapor from the propellant tank into the storage tank, creating a pressure differential between the tanks, and allowing ammonia to flow into the propellant tank.

Gaseous oxygen is supplied to the cascade by the vendor's truck. Gaseous nitrogen is piped from a high-pressure pumping station which already serves the rest of the test areas.

With one exception, all valves and controls are commercial products. Remotely controlled valves are actuated pneumatically with solenoid pilots, using 150-psi control pressure. The noncommercial items are motor-operated Grove dome loaders. In this instance, a NARTS-designed electrical drive is used to turn the handwheels of the dome loaders remotely from the control room. This avoids the lag in pressurizing tanks which would occur with dome loaders in the control house connected to the stand by 250 ft of tubing. Since there are no high-pressure gas lines in the console, the hazard of gas pressure explosions is removed.

5 Instrumentation

Instruments are installed to measure the usual rocket engine parameters: pressure, force, flow rate, and temperature. Enough channels are provided to allow for any additional measurements which might be needed for a complete engine test.

There are 96 signal input plugs in the test cell, each connected to a four-wire circuit. The total number of installed recording channels includes 35 potentiometer recorders, eight direct writing Sanborn recorders, and a two-channel cathode-ray oscilloscope. Terminations are also installed in the recording racks for two 18-channel magnetic oscillographic recorders. There are thus 79 allocated recording channels with 17 spare circuits available.

The basic system uses direct current excitation of the pressure and force pickups. Space is provided in the racks for incorporation of an a-c carrier system termination if desired. The d-c system requires no amplification with the usual strain gage transducers, and sufficient output is available from these to excite a magnetic recording oscillograph element at frequencies to 100 cps. The recording of pressure, thrust, and flow frequencies above 100 cps was deemed unessential in ordinary development of large engines.

The outputs from the transducers can be fed as desired to either self-balancing chart recorders, magnetic oscillographs, or direct writing-pen recorders. A low gain d-c amplifier was built into the system feeding the direct writing recorders, even though d-c amplifiers generally have been avoided due to their drift. These d-c amplifiers incorporated an input circuit giving automatic compensation for the d-c level in the transducer output. Where a turbine-type flowmeter is employed, the signals are presented as an a-c signal of varying frequency. This is converted to a steady d-c voltage by means of six integrator channels. The d-c voltage level varies with the signal frequency. The integrators are almost linear to 400 cps and include multivibrator count-down circuits to handle higher frequencies.

The self-balancing chart recorders may be seen in the general view of the instrument consoles, Fig. 10. Twenty-two of the 35 recorders have a 1-sec pen traverse time and may be switched to definite ranges of 3, 10, 30, and 50 mv. The zero may be shifted smoothly over a range of ± 50 mv. This feature allows exact zero balance of a recorder by an operator prior to firing or calibration without resorting to the central jack panel. The main balance and control section of the jack panel contains 36 channels, each with individual voltage con-

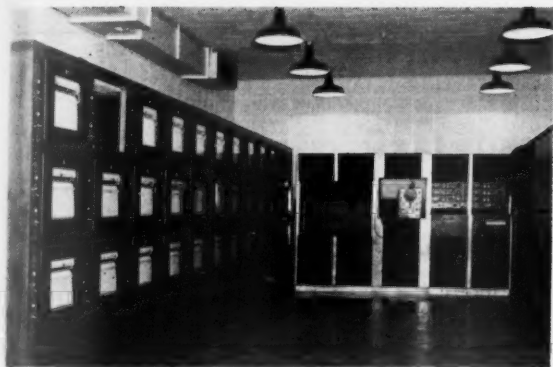


Fig. 10 Interior of control room

controls. The output signals from the main balance panel are terminated on the jack panel and are available as an input signal to any of the recorders. Thirteen of the recorders are normal 10-mv units with 2-sec traverse rates which are generally useful where the signals are of reasonable level. They represented a considerable cost saving over the 22 multisensitivity, 1-sec traverse recorders.

Calibration of this system is done by placing shunts across the bridge arms, by the use of remote-controlled relays installed in the balance unit. Included in the equipment is a high precision potentiometer by which the chart recorders may be checked for linearity and absolute scale calibration.

In addition to the purely electrical calibration system, a pair of high precision Heise gages are installed in the cable termination room. Over-all system calibration of pressure pickups is effected with these, using controlled nitrogen pressures.

A 100-cycle high precision frequency standard is used to simulate turbine flowmeter signals. This gives an absolute calibration of frequency vs. d-c millivolt output.

Temperature measurement will, in most cases, be made by means of thermocouples. A cold junction in the test cell allows the use of copper leads throughout. The low range of 3 mv is sufficient to give satisfactory sensitivity for the usual thermocouple voltages generated.

Each of the lead-covered main signal cables connecting the jack panels with the test cell junction boxes contains 60 pairs of wires. Each pair is twisted and individually shielded by metallized paper. Their exceedingly low leakage factor of 5000 megohms/mile is responsible in part for the stable operation of the system. Measurement of cross talk between adjacent pairs indicated that less than $1/20,000$ of the signal was transferred. These cables were also used extensively to interconnect the recorder racks in the control room.

Special care was given to the problem of noise and hum elimination in the signal circuits. All 60-cycle power and d-c control lines are grouped in isolated conduits. D-c excitation voltages for the pickups run in separate ducts with the signal circuit cables. All d-c return paths are taken to common low resistance busses before returning to the negative of the d-c power supply. Return currents from all relays in the instrument racks run to these negative busses.

The cell junction box is equipped with hermetically sealed plugs and protective caps to eliminate corrosion of the pins. The four wire circuits terminated at these plugs run to the control-room jack panel and connect to standard receptacles. One receptacle is used for each pair of voltage excitation leads; the second for each pair of signal output leads. Considerable flexibility of connection is thereby possible.

All electrical functions in the test cell are controlled remotely through d-c relays, powered by a Nobatron rectifier in the test cell. This obviates the use of heavy cables which would be required to avoid the presence of ground currents between the control room and the test cells. An a-c relay controlled on the operator's console, drawing its voltage from

the test cell a-c line, closes the main switches supplying power to the Nobatron. Thereafter all control switching utilized this test cell source of power. All solenoids are wired so that the operator's control board shows no light until power is actually applied to the solenoid.

Tank and line pressures are indicated to the operator by a bank of sensitive panel meters whose scales are marked in increments of pressure. The signals for these meters are derived from miniature potentiometers actuated by modified bourdon tube gages in the tank rooms. Using standard components, the over-all accuracy of this telemetering system proved surprisingly high, ranging from 1 per cent to 2 per cent. Using the panel meters, it is possible to indicate the signals recorded on the chart recorders, through transmitters and a separate jack panel.

Control of the potentiometer chart motor drives, the oscillograph motor drives, and the direct writing Sanborn chart drives is possible in three ways: at the unit itself, at the instrument jack panel, and finally through the recorder switch in the control console.

The first over-all test of the instrument installation was made during stress tests of the engine mount, using strain gages. Although the potentiometer chart recorders were used at their most sensitive setting of 3 mv and the signal levels were extremely low, no observable drift or noise was noticed throughout the test.

6 Utilities

The main requirement for raw water is for jet cooling and fire fighting. Raw water is supplied to the stand from a 5,000,000-gal reservoir 1809 ft away, through 8-in. cast-iron pipe laid underground. The reservoir is at an elevation of about 170 ft below the stand, making it necessary to use pumps. Three 1000-gpm, 125-psi pumps, driven by diesel engines, located at the reservoir are used.

Potable water, used for drinking, sanitary services, safety showers, hose outlets, and for filling the tankage as needed, is supplied through an 8-in. line. It is recognized that some of these functions could ordinarily use raw water, but it should be borne in mind that raw water is available only when the pumps are running, whereas potable water is available at all times.

The stand has a deluge system which supplies water to sprinklers and floor flushes in each tank room, and to the working floor. These can be actuated remotely from the control room by solenoid-operated quick-opening valves with manual reset. Station-operated fire trucks can be called through a Gamewell System. Hydrants are located at points around the stand for the use of fire-fighting equipment.

A central heating plant, located in the lower level of the control house, supplies steam to unit heaters in both buildings. The necessity of working for long periods with both ends of the room open, and the use of uninsulated sheet-metal siding, presented a heating problem. However, a large unit heater is provided to afford some comfort to personnel during winter operations. The control room is air conditioned primarily to avoid instrumentation difficulties caused by high humidity. Other ventilation is standard, except for the tank rooms, which have forced draft blowers to aid in clearing out fumes.

Power is brought to the area by a 2300-volt 75-kva transmission line. A substation reduces this to 220- and 110-volt power. Lighting is standard, except for the firing balcony, which is lit by explosion-proof light. Street lighting and floodlighting are provided for night work and security patrols.

7 Construction

Construction was started on Nov. 19, 1951. Completion of the stand, including installation of instruments and controls, was scheduled for Nov. 30, 1952. By the end of February 1952, excavation had been completed, and structural steel

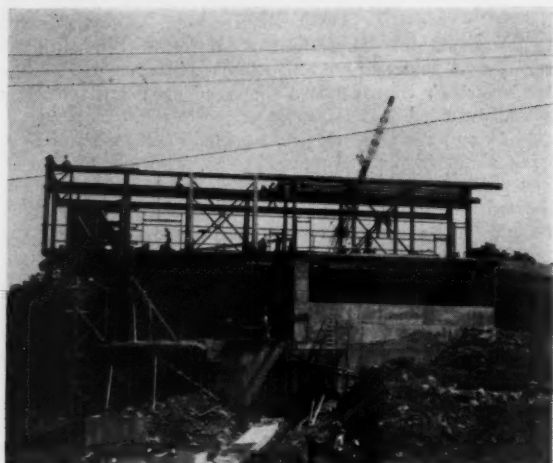


Fig. 11 Test stand during construction

and concrete were in the process of erection. By the end of August 1952, the basic structure was completed, the installation of the process piping, controls, and instrumentation remained to be done. Delays in the procurement of the large ammonia and water tanks, due to a steel strike, were the principal causes of the stretch-out of the completion date. The last major item, the coolant tank, was delivered early in April 1953. This was installed and checked immediately, and the stand was turned over to its first user for engine development on May 1, 1953. Fig. 11 shows the stand during construction. Fig. 12 is the completed test facility.

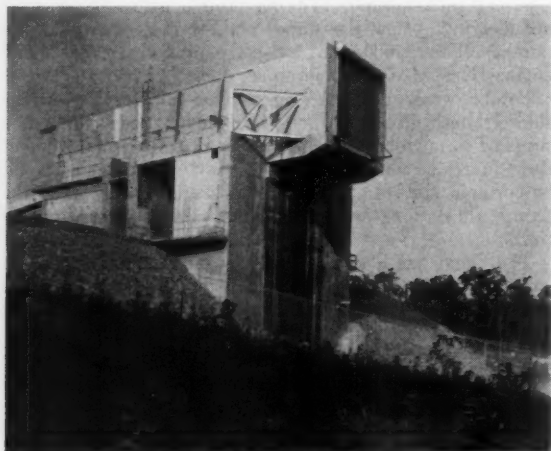


Fig. 12 Completed test facility

In the construction of the stand, 3830 yd of earth were excavated, 1500 yd of rock were blasted, 3230 yd of concrete were poured, and 650 tons of steel were used.

8 Participation by the NARTS

Aside from the over-all direction of the project, the Naval Air Rocket Test Station was completely responsible for the instrumentation and control systems. The station designed, procured, fabricated, and installed all instrumentation. Pneumatic controls, including solenoid valves, dome loaders, and the interconnecting tubing were also designed and installed.

Acknowledgments

The preliminary and detailed structural design was done by Frank Grad & Sons, Raymond Commerce Bldg., Newark, N. J.

The general construction contractor was the E. M. Waldron Company, 84 South Sixth Street, Newark, N. J.

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JET PROPULSION

An Air-Transportable Liquid Oxygen Generator— Its Operation and Application

G. A. BLEYLE,¹ R. B. HINCKLEY,² and C. L. JEWETT³

Arthur D. Little, Inc., Cambridge, Mass.

The design and operation of a lightweight air-transportable liquid oxygen generator, constructed for the U. S. Air Force, are discussed. This plant, which operates on a low-pressure cycle, separates oxygen from air at the rate of 10 tons per day. Unique design features include a special type heat exchanger, aluminum construction, gas-turbine-driven air compressor, and skid-mounted sections for loading into standard cargo aircraft. The 99.5 per cent liquid oxygen produced can be used in rocket propellant systems, for breathing purposes, and for welding and cutting applications.

Introduction

IN THE latter part of 1946 it became apparent that there were extensive military needs for equipment to produce oxygen at advanced military bases. At that time, the supply of oxygen was limited to that which could be transported as compressed gas in steel cylinders or could be produced by relatively small-capacity oxygen generators. With a view toward having an adequate global supply of oxygen, the Aero Medical Laboratory of the U. S. Air Force had the foresight to initiate a program for the development of a large-scale liquid oxygen generator. (Recently, work on this generator has been under the direction of the Equipment Laboratory of the Wright Air Development Center.) For maximum mobility, it seemed desirable to have a plant that was as lightweight as possible and that could be air-transportable. An oxygen generator based on the fractionation of air seemed most promising. A set of design specifications covering such a plant was given to Arthur D. Little, Inc.

First on the list was the requirement that the plant be capable of separation into individual packages for loading into standard cargo aircraft. Transport aircraft designated the C-74, C-82, C-97, and C-119 were to be used and, commensurate with these, the capacity of the plant should be in the neighborhood of 500 to 1000 lb/hr. In keeping with the objective of minimum size and weight, it was specified that this oxygen generator should be self-sufficient, except for fuel, lubricating oil, and a small amount of electric power for the instruments, and that lightweight materials should be used wherever practical. The equipment was to be air-cooled throughout instead of water-cooled, for ease of supply and to eliminate the freeze-up problem during winter operation.

Safety and simplicity of operation were important since the plant was to be run by relatively inexperienced personnel with minimum supervision from the technical staff. The uses to which the oxygen were to be put, that is, breathing, welding and cutting, and rocket propulsion, require 99.5 per cent pure oxygen output. Finally, it was emphasized that the design of the plant must further the art of liquid oxygen production.

Cycle Selected

After thorough study and evaluation of these requirements, it became apparent that a low-pressure (approximately 105 psia) cycle with reversing exchangers was best suited for several reasons. Water vapor and carbon dioxide, contained in the air as impurities, are removed by solidification and reevaporation within the reversing heat exchangers, rather than by the chemical means incorporated in high-pressure plants (2000 to 3000 psia). This eliminates a continuous chemical supply problem at advanced bases and makes possible a plant that is self-sufficient except for a supply of compressed air. A low-pressure plant has a weight advantage because of the light-gage materials used in construction. Heavy-gage materials are necessarily used in high-pressure plants. Further, the low-pressure cycle has a decided safety feature, particularly since it will be operated by relatively inexperienced personnel and subject to possible shell fragments. The other design specifications were also satisfied by this low-pressure cycle.

Fig. 1 is a simplified flow diagram of the process. Atmospheric air at the rate of 18,720 lb/hr is compressed to approximately 105 psia. The compressed air then passes through an aftercooler where it is cooled to within 20 F of the ambient air used as the cooling medium. Use of the aftercooler is necessary since the temperature of the air leaving the compressor is too high for the materials used in the oxygen generator. The aftercooler is not shown in this simplified diagram.

The compressed air leaving the aftercooler flows through a reversing valve and enters the heat exchanger which is designed to perform two functions: to cool the incoming air almost to the liquefaction temperature, and to remove the water vapor and carbon dioxide from the air. In one channel of the exchanger, the compressed air is cooled to approximately -270 F by heat exchange with the nitrogen-rich effluent stream and with an unbalance stream. This unbalance stream compensates for the difference in specific heats and mass flow rates between the air and effluent streams. In the cold parts of the exchanger the greatest percentage of the carbon dioxide contained in the air is solidified as "snow" on the surface of the channels. Reversing valves are actuated several times per hour by an automatic timer, interchanging the channels through which the air and effluent nitrogen flow. Thus, the carbon dioxide and water frozen out of the air on the channel surfaces during the previous cycle are re-evaporated and carried out in the effluent nitrogen.

When the compressed air leaves the heat exchanger at -270 F, it divides into two major streams, one of which flows to the rectifying column and the other flows to the expansion turbine. Part of the compressed air on its way to the turbine bypasses through the exchanger to provide the unbalance stream mentioned previously. This, later, rejoins the stream going to the expansion turbine and, by remixing, produces the desired expansion turbine inlet temperature of -246 F. The air flowing through the expansion turbine undergoes a pressure change from 105 psia to 25 psia with a resultant temperature

Presented at ARS Summer Meeting, Los Angeles, July 2, 1953.

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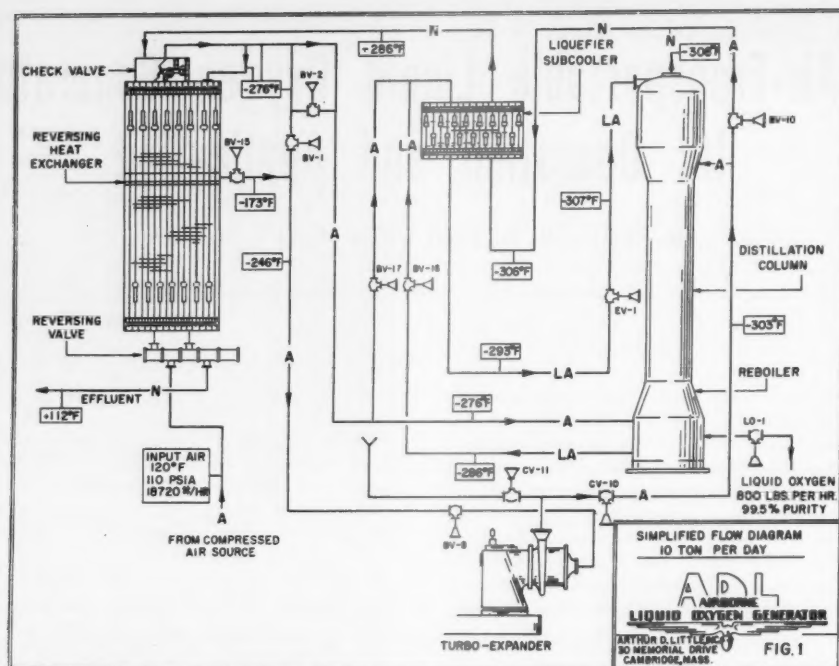


Fig. 1 Simplified flow diagram of 10-ton-per-day, airborne, liquid oxygen generator

change to -304°F , thereby providing refrigeration for the process. The energy produced by this expansion is used to run a blower which provides cooling air for the compressor after-cooler. From the expansion turbine the low-pressure air flows to the rectifying column, where one portion flows to the contacting section of the column while the other bypasses the column and joins the effluent leaving the column.

Part of the air to the rectifying column flows through a condensing coil in the reboiler section of the column where it is liquefied, while the remainder by-passes the condensing coil. The heat of condensation released by the condensing air boils the liquid surrounding the coil and supplies the heat input required for operation of the column. By control of the quantity of air flowing through the condensing coil, the heat input

to the column can be regulated to permit variation of product purity at the operator's discretion.

The liquid air from the condensing coil mixes with the by-passed vapor and the mixture flows through a liquefier subcooler, where the remaining vapor is condensed and the total quantity of liquid is subcooled to a temperature of -293°F . The liquid leaving the liquefier-subcooler flows through an expansion valve, where it is further cooled to -307°F , and then to the top of the rectifying column.

The liquid flowing down through the column first encounters the expansion turbine exhaust and then the vapor rising from the reboiler. This countercurrent flow strips nitrogen from the descending liquid and condenses oxygen from the rising vapor. Progressively, the liquid becomes richer in oxygen until it is essentially pure liquid oxygen in the reboiler,

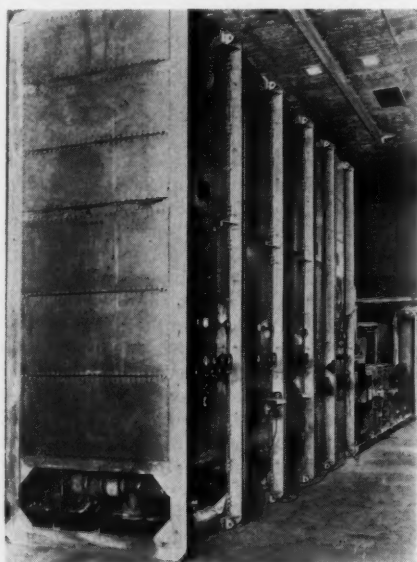


Fig. 2 Airborne liquid oxygen generator in operation, with reversing heat exchanger elements in foreground

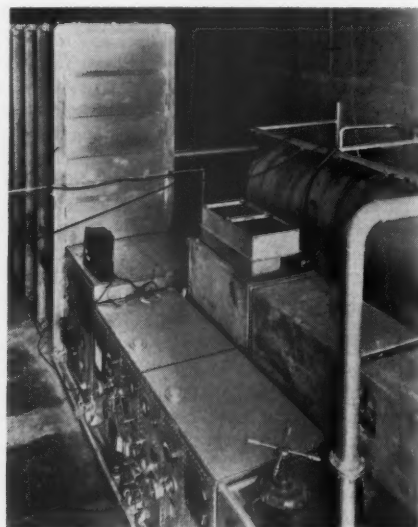


Fig. 3 Airborne liquid oxygen generator in operation, with expansion turbine elements in foreground

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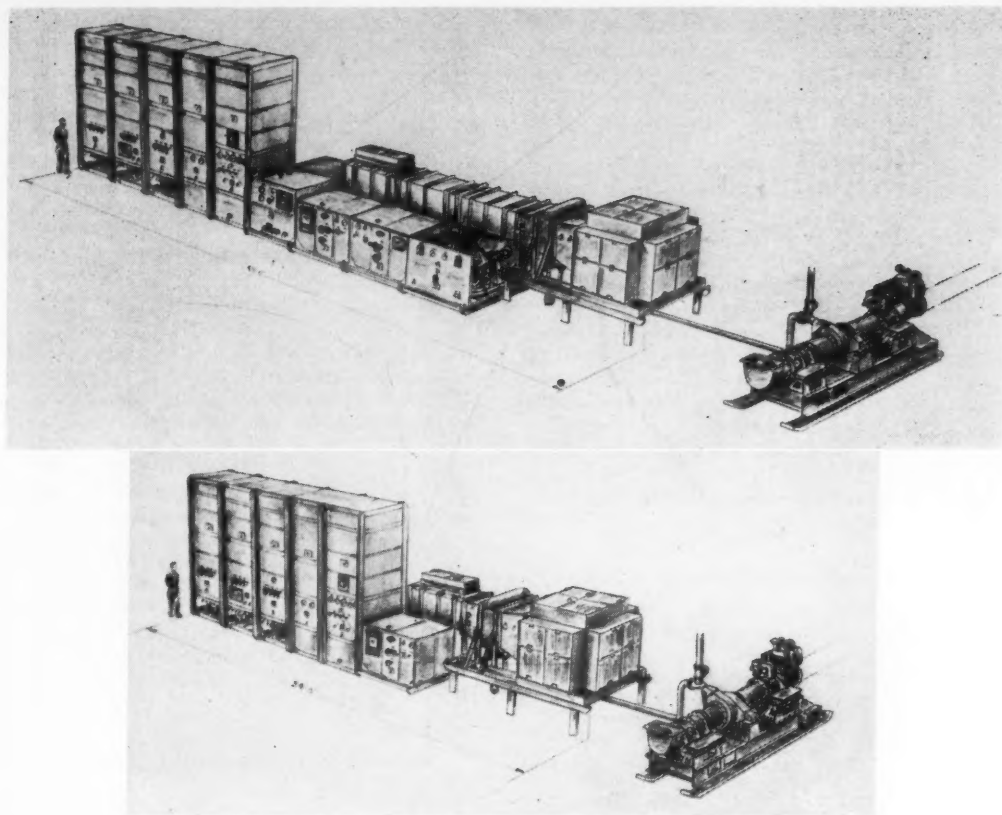


Fig. 4 Liquid oxygen generator, showing original and simplified designs

from which it flows to storage containers. The column is packed with wire cloth saddles which distribute the liquid in thin films for more intimate contact with the vapor. The use of this packing permits a smaller diameter column than does the conventional bubble tray type, thereby materially reducing the over-all weight of this piece of equipment.

The nitrogen-rich vapor rising from the column joins the expansion engine exhaust and flows through the liquefier-subcooler and heat exchanger, where it cools the countercurrent stream of compressed air to the temperature levels previously discussed.

Summarizing this cycle briefly, compressed air is cooled and liquefied in heat exchangers and finally separated into its major components of oxygen and nitrogen in a rectifying column. The refrigeration for cooling and liquefaction is obtained from the adiabatic expansion of a major portion of the input air in an expansion turbine. The liquid oxygen obtained from the separation is withdrawn as product; the nitrogen joins the exhaust air from the expansion turbine and the mixture is vented to the atmosphere after being used to cool the incoming air.

The existing plant was designed solely for liquid oxygen production; however, with minor modifications to the rectifying column it could produce either liquid oxygen or liquid nitrogen of 99.5 per cent purity at essentially the same capacity. Figs. 2 and 3 were taken at opposite ends of the plant. Fig. 4 is an over-all sketch.

Operation of Air-Transportable Generator

To operate this plant on a 24-hour basis, two or three technicians would be needed per 8-hour shift, with an engineer on call. Actually only two controls require attention: the quantity of air to the reboiler coil, and the setting of the expansion valve.

From a time standpoint, this generator will begin producing 99.5 per cent pure liquid oxygen at the rate of 800 lb/hr in 4 hours from a warm start. Also little time is lost on maintenance and repairs. For example, the exchangers can be defrosted, if necessary, and the generator put back into full production in 1½ hours. If major internal repairs should be required, the plant can be brought up to room temperature in 8 hours after shutdown.

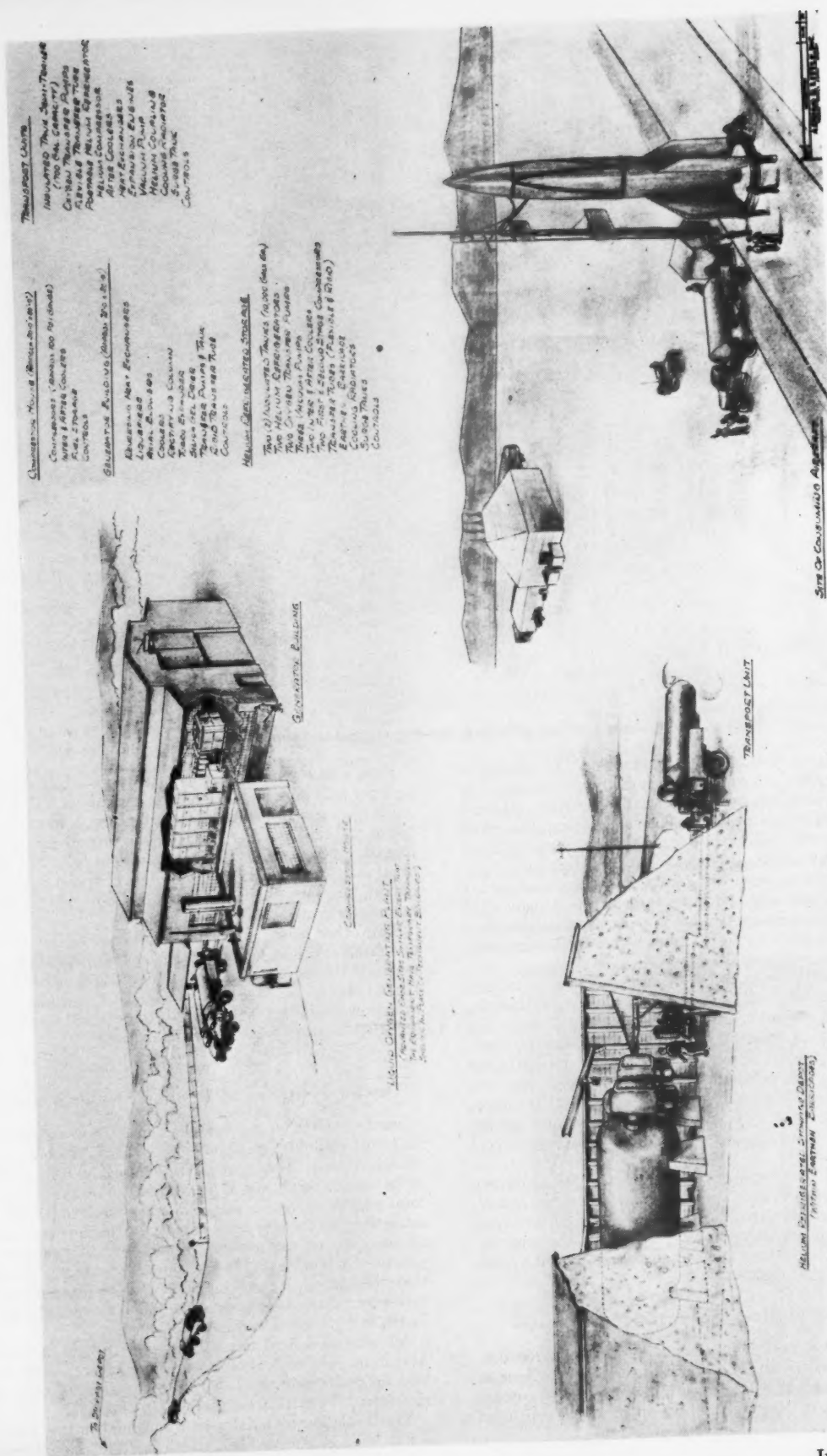
Two other points are of interest in the operation of this generator. Although the cooling air from the aftercooler is normally ducted to the atmosphere, it could be used to heat the building housing the equipment in cold climates. Also, no attention is required if the plant is to be left idle or stored indefinitely, since no water is used as coolant.

Design Features to Reduce Size and Weight

Since one of the major specifications for this generator was air transportability, minimum size and weight were constant considerations. As designed, the plant was 49 ft long, 14¾ ft at its highest point, and 11 ft deep at the widest point. The total weight, excluding the compressor, was 43,000 lb. Because this was the first plant of its type, the life expectancy of all components was not known and several duplicate components were included. In the course of testing, it was found that this precautionary duplication of equipment was unnecessary. Removing these spare items reduced the over-all length to 34 ft and the weight to 35,000 lb.

All construction materials were kept as light as possible. Aluminum was used wherever feasible; in fact, to the extent that approximately one half the total weight is made up of aluminum.

The insulation material used throughout in this plant is a fine bulk glass-wool fiber, which has the characteristic of



low weight together with high insulating efficiency. In addition, this type of glass wool can be readily handled without special equipment or protection for the operators, thereby simplifying maintenance of the unit.

Substantial weight savings will be achieved in the ultimate air compressor design. Initially, a survey was made to determine whether any available air compressors would have the requisite low weight-capacity ratio. It became apparent that the use of standard reciprocating compressors would add greatly to the over-all weight. A gas-turbine-driven rotary compressor seemed best suited for such an advanced plant design. Since a compressor of this type did not exist, development of a design suited to specifications was initiated and is now being completed.

Because the oxygen generator section of the plant was completed before the gas turbine, multiple industrial reciprocating compressors were used in the initial tests. Since the gas-turbine-driven compressor will not be completed in time to meet a specific operating date, an alternate air compressor is now being constructed in our shops. This compressor consists of three-stage, diesel-driven rotary blowers of the Whitfield type. Each stage is suitable for air transportation, although somewhat heavier than the gas-turbine compressor which will ultimately be used. For comparison, the gas turbine will weigh about 7000 lb while the over-all weight of the diesel-driven rotary blowers is about 60,000 lb. Our original compressor survey indicated that several diesel-driven reciprocating compressors would have to be manifolded together because of size limitations imposed by the aircraft, raising the weight to about 90,000 lb.

Applications and Storage of Liquid Oxygen

Fig. 5 shows an artist's conception of the use of liquid oxygen from this generator, through storage, and ultimate application. By locating the oxygen generator at some central point, it could supply several firing sites. From the generator, the liquid oxygen could be piped or trucked to large tonnage storage tanks. For road transport, trailer trucks with a capacity of 3700 gal of liquid oxygen are feasible. These trucks can be equipped with low head pumps and insulated hoses for transfer operation. Where high pressures are needed, reciprocating pumps can be used to obtain pressures up to 5000 psig or more.

The storage of liquid oxygen is no longer a problem, since liquid oxygen can be maintained for an indefinite period of time by the use of helium refrigeration. Helium refrigerators circulate cold helium gas in a closed cycle through condensing coils in the top of the storage tanks, thereby condensing all of the vaporized oxygen. Several helium refrigeration systems for the storage of liquefied gases have been built by Arthur D. Little, Inc. Subsequent field use of this equipment has definitely demonstrated the feasibility of such systems.

The advantages of helium refrigeration for liquid oxygen storage are numerous. For example, large quantities of liquid oxygen can be stored at any location remote from the generator, with no loss from evaporation. Operation of a large-scale liquid oxygen generator for topping off the storage tanks is avoided, with power requirements for refrigerators far less than for oxygen generators. In addition, the helium refrigerator is essentially an automatic piece of equipment, requiring only occasional attention.

Another method of keeping the storage tanks full would be to have small liquid oxygen generators at the storage site. However, this method requires fairly constant attention.

Conclusion

The generator for producing liquid oxygen described here has been successfully tested and meets the Air Force specifications. It is self-sufficient, requiring only fuel and lubricating

oil. It is believed to be the first such plant that needs no auxiliary cooling water. It can be separated into several individual sections for air transport, with the obvious corollary advantage of easy replacement of major component parts. It incorporates unique design features to meet the requirement of minimum weight—a special type heat exchanger with perforated aluminum plates, use of a gas-turbine-driven axial flow air compressor, and a packed-type fractionating column. The liquid oxygen produced is 99.5 per cent pure. In particular, the Air Force has been provided with an efficient and versatile plant that should, among other uses, greatly simplify the logistics of missile propellant supplies.

The generator can be adapted to produce either liquid oxygen or liquid nitrogen, should high-pressure nitrogen be needed in the missile control system. The same storage, handling, and pumping equipment can be used. This particular liquid oxygen generator will be utilized at the Patrick Air Force Base in Florida.

The development of large-scale, transportable liquid oxygen generators together with helium refrigeration systems has demonstrated the practicability of producing and maintaining liquid oxygen in any quantity at advanced military bases.

Supplemental Reading⁴

1 "Large-Scale Production and Handling of Liquid Hydrogen," by H. L. Copen, *Journal of the American Rocket Society*, vol. 22, 1952, pp. 309-323.

2 "Production of Oxygen for Industrial Purposes," by W. Lobo, *Chemical Engineering Progress*, vol. 1, 1947, pp. 1 and 21.

3 "The Liquefaction of Helium by an Adiabatic Method," by P. Kapitza, *Proceedings of the Royal Society of London*, vol. (A) 147, 1934, pp. 189 and 193.

4 "Air Liquide, Oxygene, Azote, Gaz Rares," by Georges Claude, Paris, 1928.

5 "Expansion Turbines Producing Low Temperatures Applied to Air Liquefaction," by P. Kapitza, *Journal of Physics, USSR*, Moscow, vol. 1, 1939, p. 1.

6 "Low Temperature Research is Aided by Simplified Helium Liquefaction," by A. Latham, Jr., and H. O. McMahon, *Refrigeration Engineering*, June 1949.

7 "Chemical Engineers Handbook," edited by John H. Perry, McGraw-Hill Book Co., Inc., New York, 3rd Edition, 1950, pp. 1701-1717.

8 "Chemical Engineering Thermodynamics," by B. F. Dodge, McGraw-Hill Book Co., Inc., New York, 1944, pp. 456-473.

9 "Oxygen Manufacture Thermodynamic Analysis of Processes Depending on Low Temperature Instillation of Air," by Bliss and Dodge, *Chemical Engineering Progress*, vol. 45, 1949, pp. 51, 129.

10 "Large Scale Production of Oxygen and Atmospheric Gases," by Clark, BIOS Final Report 591, PB 41229 (1946).

11 "Large Scale Production of Oxygen," by Carlsmith, F I.-A.T. Final Report 1120, PB 88840 (1947).

⁴ These references were supplied by one of the editors in the hope that they would be helpful to the reader who might wish to go more deeply into the subject matter of this paper.

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A New Supply System for Satellite Orbits—Part I

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The subject of orbital supply is investigated, stressing the engineering possibilities for improving the economic aspects of orbital operations and space flight. Following a brief survey of the basic problems, a new orbital supply system is proposed in the second section of this paper. It is characterized by operational separation of cargo supply and passenger transport. The supply ship has a ballistic shape and is automatically guided into the target orbit. The passenger ship is equipped with a winged upper stage. In the third section, supply requirements for orbital operations as well as space flight are discussed. The existence of optimum satellite orbits for departure and arrival of interplanetary expeditions is demonstrated analytically. Finally, examples of guided supply vehicles and passenger ships are presented. Their take-off weight and payload capacity serve to illustrate the effect of supply requirements on the over-all supply efforts.

Nomenclature

D	= dead weight fraction of gross weight = $W_d/W_0 = \gamma_e + \delta + \sigma$
E	= empty weight fraction of gross weight = $W_e/W_0 = \lambda + \gamma_e + \delta + \sigma$
ΔE	= increment (or decrement) of gravitational energy
F	= thrust
F_n	= net weight factor = $\frac{N}{N + \Delta}$ (design quality parameter)
g	= gravitational constant
h	= altitude
N	= net weight fraction of gross weight = $W_n/W_0 = \alpha + \gamma_e + \delta + \sigma$
n	= load factor
R	= distance from the center of the sun
r	= distance from the center of the earth
r_{00}	= radius of the earth
t	= time
V_{st}	= absolute velocity of departure with respect to the home planet
v_c	= circular velocity
v_{td}	= ideal velocity (burn-out velocity in absence of gravitational and drag losses)
v_I	= circular speed at distance r_I
W_d	= dead weight = $W_{\gamma_e} + W_{\delta} + W_{\sigma}$ (weight of all hardware)
W_e	= empty weight = $W_d + W_{\lambda} + \Delta W_{\lambda}$ (weight of all hardware plus payload)
W_n	= net weight = $W_{\alpha} + W_{\gamma_e} + W_{\delta} + W_{\sigma} = W_0 - (W_{\lambda} + W_{\lambda} + \Delta W_{\lambda})$ (weight of everything except propellant for propulsion and payload)
W_0	= gross weight
W_p	= over-all propellant weight = $W_{\lambda} + W_{\alpha}$
W_{α}	= weight of auxiliary fluid for prime mover of feed system
W_{γ_e}	= weight of guidance, control, power, and equipment (communication, instrumentation, environmental installations)
W_{δ}	= weight of power-plant group installed (containers, feed system, power generator, motor, piping, plumbing)

W^A	= weight of propellant for propulsion
W_{λ}	= payload weight
ΔW_{λ}	= additional payload weight and reserve weight
W_{σ}	= weight of structural group (body hull, wing group, tail, or fin group)
α	= W_{α}/W_0
γ_e	= W_{γ_e}/W_0
γ	= gravitational parameter
δ	= W_{δ}/W_0
θ	= trajectory angle (flight direction to horizon)
Λ	= W_{Λ}/W_0
λ	= W_{λ}/W_0
σ	= W_{σ}/W_0
φ_p	= W_p/W_{λ} = propellant weight factor
φ_d	= W_d/W_{λ} = dead-weight factor (referring to all wingless stages)
φ_d'	= dead-weight factor, assuming parachute recovery of wingless first stage in addition to any winged stage
φ_0	= W_0/W_{λ} = take-off weight factor

Subscripts

A	= aphelion or apogee
opt	= optimum
P	= perihelion or perigee
R	= arbitrary distance from the sun
r	= arbitrary distance from the earth
s	= satellite
I, II, III, IV	= propulsion phases I through IV
0, 1	= initial- and cut-off condition, respectively
\oplus	= earth
\odot	= sun
1, 2, 3	= stage numbers
\varnothing to PL	= astronomical symbols for planets from Mercury to Pluto

Introduction

THE concept of artificial satellites has been discussed at length by H. Oberth who, in his fundamental book (1)² already covered many functions pertaining to an observational station. Their significance for interplanetary flight was emphasized by G. Von Pirquet in a series of theoretical papers (2). Thus, the principal aspects and implications of artificial satellites were clearly recognized in the third decade of this century.

With the realization and comparative perfection of the liquid propellant rocket, attention has been shifted to the problem of their establishment and maintenance. This problem has two aspects, an engineering and an economic aspect, which are of particular importance. Indeed, their correlation is so significant that an engineering concept which fails to consider the economic angle can hardly contribute effectively to a solution of the problems involved.

The four fundamental problems facing the engineer can be stated briefly: (a) How to carry a heavy and sometimes bulky payload into space at a minimum of development efforts for the carrier and a minimum of expenses per unit weight of payload. (b) How to carry humans safely out of space, through the region of intense frictional heating and difficult aerodynamic conditions, back to earth. (c) How to minimize the

Revised manuscript received November 2, 1953.

¹ Preliminary Design Department. Mem. ARS.

² Numbers in parentheses refer to References on page 309.

supply requirements for a given operation in space. (d) How to provide the environmental conditions for human existence in space.

The first two problems are discussed in connection with the system of orbital supply in the subsequent section. Attention is given to the third problem in the section thereafter, while the last problem is beyond the scope of this paper. Progress toward their solution can be expedited substantially by recognizing two very important requirements which are not always fully taken into account: (a) Small supply ships should be used, even for large-scale load transfer, in order to avoid unduly specialized and costly vehicle development and production. (b) Every effort should be made to boost the transport efficiency, that is, to lower the amount of propellant weight and weight of hardware expended per pound of payload. High transport efficiency is the key to a reasonable satellite supply economy with thermo-chemical or thermo-nuclear rocket vehicles.

It can safely be assumed that if manned space flight, based on chemical propellants, is to be realized in this century, the largest single vehicle involved must not weigh more than two million pounds, preferably less than 1.5 million pounds. Even with the present development pace in high gear, it would take at least 20 years to develop prototype vehicles of this size, to say nothing of bringing them to a status of perfection adequate for the transport of humans. The most important consequence of such a restriction is that payloads of a few thousand pounds only are acceptable for the individual vehicle, and that inhabited orbital installations must be established on that basis or not at all in the foreseeable future.

For a better appraisal of the long-range development aspects, a distinction shall be made here between three classes of rocket-powered vehicles: the terrestrial, the orbital, and the astronomical class. The range of their take-off weights is shown in Fig. 1 as function of the ideal velocity requirements and of the payload weight. The limiting speed for terrestrial vehicles is circular velocity just above the tangible atmosphere, corresponding to an ideal velocity (which includes all losses due to drag and gravity) of 29,000 fps; payload weights probably will be within the 10,000 lb limit. These mechanical

energy requirements indicate a maximum take-off weight of the order of 1.5 million pounds for terrestrial vehicles, based on propellant exhaust velocities of the order of 8-10,000 fps. The minimum ideal velocities for Moon and two planets (round-trip) are indicated for the astronomical class, as well as the range of space ship take-off weights. These weights can be kept comparatively small, because of payload and propellant weight distribution among a number of vehicles. Therefore, the space ship take-off weights can be of the same order of magnitude as that of the larger terrestrial vehicles.

The ideal velocity required for the orbital (satellite supply) class exceeds the limit for terrestrial vehicles by a small margin only, being about 32,000 fps. The difference is due to the somewhat greater altitude of permanent orbits ($h > 500$ n.mi.). Nevertheless, take-off weights are sometimes proposed which exceed those of the two other classes by a factor up to about six, because of the rather high payload weights assumed and of a poor transport efficiency. This results in a considerable "hump" in the development line, as indicated in Fig. 1. Such course is difficult to accept; it constitutes, in fact, an unnecessary obstacle, delaying, more than expediting, the realization of space flight. The hump can be avoided, for instance, by applying either one of two methods, or both together. The first method, payload transfer, has been discussed in an earlier paper (3); the second method, use of automatic supply ships, is the subject of the present paper.

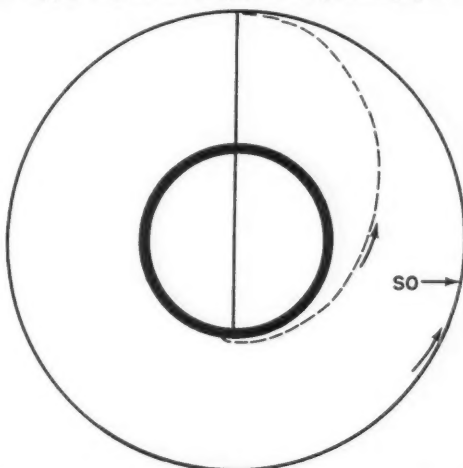


Fig. 2a Direct earth-to-orbit flight (SO = satellite orbit)

A discussion of satellite supply usually is based on the assumption of direct earth-to-orbit flights (Fig. 2a). Yet, as the orbital distance from the center of the earth increases, the accumulation of energy in the individual ship must become larger and, unless the payload capacity is reduced drastically, soon leads to impracticable vehicle dimensions and take-off weights.

In reference (3) a supply system has been proposed which permits the use of small supply vehicles for any orbital operation. The principle is sketched in Fig. 2b. Briefly, it is based on the assumption that each orbital installation revolving beyond about 500 nautical miles altitude can be equipped with a space ferry which maintains connection with a coplanar orbit, just above the atmosphere, termed auxiliary orbit (AO). In this orbit, small orbital carriers from the surface meet the space ferry and transfer payload to it. The individual carrier must have high flight performance, hence, transports a small payload weight. The space ferry whose flight performance is much smaller, can accommodate a larger payload. For this reason both types can be kept comparatively small. Carriers having less than two million pounds take-off weight can be used. They may originally have been built for terrestrial purposes. No special development of larger vehicles is necessary.

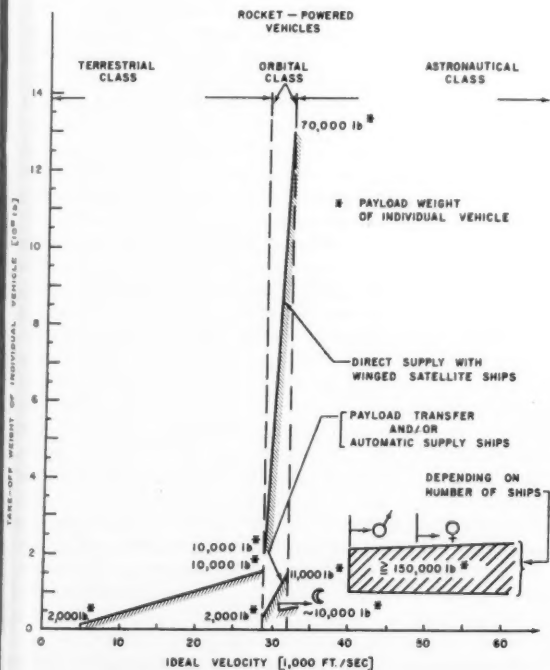


Fig. 1 Three classes of rocket-powered vehicles

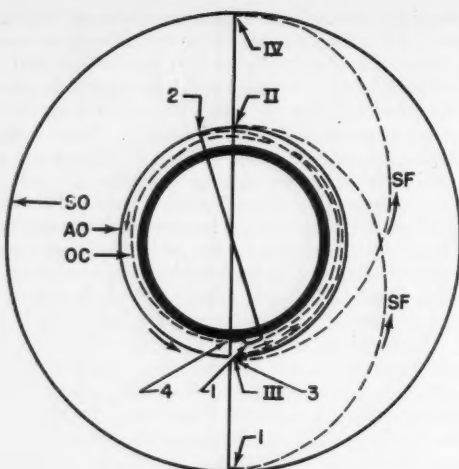


Fig. 2b Payload transfer in auxiliary orbit
AO = auxiliary orbit; SF = space ferry; OC = orbital carrier
Supply process: (1) SF leaves SO; establishes AO (II);
(1) OC leaves earth to meet SF in (2); after completion of payload transfer SF (III), returns to SO (IV), and OC (3) returns to earth (4)

By the payload transfer method the over-all energy requirement is broken down into portions which can be handled more conveniently from the engineering viewpoint. However, since the orbital carrier, in effect, represents only a down-scaled version of a large satellite ship, the transport efficiency remains essentially unchanged.

The second requirement mentioned above cannot be fulfilled satisfactorily on the basis of chemical propellants. However, substantial improvements are possible. For this purpose the over-all supply system assumed so far must be modified. In this paper it is attempted to contribute some thoughts to this effect. The results indicate that by proper rationalization of the supply system, the over-all efficiency can be improved considerably over that of previous concepts.

The Orbital Supply System

Supply ships for inhabited satellites are generally assumed to consist of booster stages and a winged and manned payload stage. For each pound of delivered payload, such a vehicle must carry an even larger additional load, consisting of wings, control surfaces, landing device, and proper environmental and safety equipment for the crew. This load is needed exclusively for the crew accompanying the payload. Since it is part of the upper stage, it produces a proportional increase in the weight of all lower stages, resulting in a poor supply economy which makes payload transport very expensive.

The bulk of delivered payload for establishing and maintaining inhabited orbital installations consists of material rather than personnel. Therefore, the main purpose of satellite ships is to carry goods rather than passengers who, in fact, represent a small fraction of the over-all weight carried into the orbit. For the reasons stated above, this weight fraction is much more expensive than the cargo weight. Therefore, it is proposed to consider the use of automatic supply ships and to separate the supply operations into material supply and passenger transport.

The elimination of crew facilities results in a payload stage of considerably lower weight for the same payload, causing, by virtue of stage principle, a substantial decrease in over-all take-off weight.

The supply ship utilizes automatic guidance during its

ascent. Even in manned ships, automatic guidance will play a dominant role throughout most of the flight, while human activity necessarily would be restricted to supervisory functions.

The guided vehicle emits radio signals which enable orbital and terrestrial stations to follow its course and determine possible deviations from the predetermined path. Approaching the target orbit, the ship is picked up by satellite guidance radar and monitored, during its final burning period (period III, cf. subsequent section) to its destination at a safe distance from the satellite. Thereby inaccuracies at the perigee cut-off point are eliminated and the satellite is protected from possible disturbance or damage by a straying supply ship.

In the case of payload transfer, the supply ships are guided into the auxiliary orbit. There they emit radio signals which permit the (inhabited) space ferry from the far-out satellite to establish its own correct orbit and pick up the payloads after a short time.

For the transport of humans into and out of the orbit, special passenger ships are proposed. Their payload capacity is limited to the number of passengers plus a crew. Emphasis is placed on safety features. This can be done within certain limits of take-off weight, since the payload weight is small.

In general, the intrinsic advantages of separating cargo supply and passenger transport are summarized below.

1 Both ships can be kept lighter and smaller, since only one type of load, goods or passengers, must be carried by a given vehicle. The resulting benefits regarding development efforts, as well as handling and launching, are obvious.

2 Each type of payload has its particular design requirements. Their separate treatment not only eliminates controversial design compromises, affecting over-all reliability and safety, but also opens new avenues of approach for consistent and efficient layouts of each type. In the supply ship, for instance, this suggests the design of a very light payload stage with space ship features rather than good aerodynamic qualities, since this stage does not return, at least not as an integral body. Certain parts, such as guidance equipment, may be returned to earth in passenger ships not loaded to capacity. The design of passenger ships can emphasize safety, reliability, and good aerodynamic shape of the upper stage without running into excessive take-off weights. The aerodynamic lift over drag ratio at hypersonic speeds in the upper atmosphere is small, about 2 to 5 between circular speed and Mach number 10. Low wave drag in the regime of continuum flow is desirable, in order to prevent excessive heating of exposed structure. Therefore, the wing loading should be small, in order to obtain high gliding altitude and low heat transfer to the skin while the vehicle is exposed to intense friction. Small wing loading, however, means more structural weight and higher gust load factors for the heated air frame. High vehicle speed and possible strong air movements at great altitudes (e. g., 4, 5, 6) tend to aggravate this situation, while reduced density will have a moderating effect. For relief by technical means, a more even distribution of lift and weight as well as other advantages of flat-bottom configurations (7) should be utilized to the fullest extent. Theoretical and experimental research in the field of hypersonic and high supersonic flow suggests shape characteristics, such as very slender bodies and wings with small thickness ratio, which make the vehicle unsuitable for stowage of bulky payload, unless it is so large that the take-off weight becomes prohibitive.

3 Absence of a crew in supply ships is an asset from the safety angle inasmuch as failures do not produce a risk of life.

4 Automatic supply ships can fly directly to the nearer target orbits, thus eliminating the payload transfer method and simplifying the supply process without sacrificing the advantages originally derived from the transfer method. Auxiliary orbits will be useful, however, when supply must be carried to a distant orbit.

5 Reduced vehicle size is advantageous for stage recovery.

Requirements for Satellites and Astronautical Expeditions

The inhabited satellite may be a marginal goal for this century's technology. In any case, the prospects for its realization in the near future depend very much on the engineering skill of concentrating a maximum of attractive features for the satellite into a minimum of efforts. This does not only call for small supply ships and efficient supply methods, but also for small orbital installations. Only then can the supply demands be kept economically manageable. Another important factor is the rotation of personnel—which actually is the most expensive process, as shown in the preceding section. The period of rotation depends on what ultimately may be regarded as maximum safe stay time in the satellite. Obviously, if this period is short, it becomes even more important to limit the number of personnel to the very minimum needed for keeping the satellite functioning.

It has been shown in reference (3) that the orbital requirements for observational satellites are not compatible with those for depot stations serving interplanetary expeditions. Therefore, these two functions cannot be combined in one installation. Indeed, as long as only chemical propellants are available, there is little point in establishing a permanent depot station at all. Interplanetary voyages will be very rare events for quite some time after establishment of the first inhabited satellite, if they are attempted at all with chemical propellants. Therefore, it is more realistic to assume that for each planned expedition the required material is assembled in a predetermined orbit, referred to, hereafter, as orbit of departure. Among other requirements, this orbit must have correct position with respect to the ecliptic plane of the target planet at the time of departure.

The first inhabited satellite probably will be a single-body installation, circling the earth in an inclined orbit at small distance. Among its many possible functions, direct or indirect (TV, radar) surface observation will be of greatest practical usefulness in the immediate future. Other assignments will cover many branches of science, utilizing to the greatest possible extent the research possibilities offered by the space station.

Among all assignments, only surface observation may be contemplated on a permanent basis. In all other cases, working programs can safely be confined to certain subjects at a time, resulting in a continual exchange of suitable personnel, preferably in co-ordination with the period of rotation required for safety reasons. By this method the number of inhabitants can be restricted to, say, not more than four at the same time. For example, one man in charge as chief engineer and chief pilot of the small satellite and its attached emergency glider; the rest being scientific personnel, however, "satellite-trained" and sharing common responsibilities and around-the-clock duties with the chief engineer. The assumption of four persons shall be made in determining part of the supply requirements.

One passenger ship should be capable of accommodating all four persons and one pilot, no other crew members being required for the automatically guided flight. The payload, therefore, will be the weight equivalent of five persons and their personal equipment, totaling approximately 1200 lb.

For a period of thirty days, four persons need approximately 326 lb of oxygen for breathing (2.7 lb per person per day plus reserve) and 840 lb of solid and liquid food (7 lb per person per day plus reserve) and a certain amount of cleaning water, depending on how much can be gained back for repeated use from condenser and purifier. Oxygen and food then constitute a payload of about 1200 lb per month. With the additional transport capacity required, the total supply load will not exceed 2000 lb. A supply ship of this capacity should be adequate for routine service. If necessary, several ships can be sent up in rapid sequence.

For establishing satellites or supplying orbits of departure,

this capacity is inadequate. Therefore, a second and larger prototype must be provided for temporary use in periods of increased supply demand. A payload of 11,000 lb has been assumed. With the propellant and performance data given in the last section, the upper stage of this vehicle is equipped with propellant containers which are large enough to be used as construction elements for the satellite body (Fig. 8). The combined set of oxidizer and fuel tanks measures 5.3 ft in diameter and has a length of 20 ft, yielding a volume of about 450 cu ft. A total of 47 such sets furnishes material for a satellite of about 20,000 cu ft volume. Its establishment, therefore, requires 47 successful flights during which a maximum payload weight of 516,000 lb is carried into the orbit. A more detailed discussion of this station will appear in a later paper.

In order to estimate the suitability of an 11,000-lb supply ship for preparation of a space expedition, the material requirements must be determined. This will be done here in a general manner for purposes of comparison.

The well-known data of the earth-moon field permit a rapid estimation of the requirements for circumnavigation of the moon with capture maneuver in a temporary satellite orbit for a limited number of revolutions. Assuming three participants and 10,000-lb payload, the required propellant weight is roughly 460,000 lb (out of 560,000-lb take-off weight), based on take-off from an orbit at 540 n.mi. altitude and on operation with liquid oxygen and hydrazine, expanding from 590 psia to 1.47 psia and yielding a specific impulse of 325 sec (assuming a velocity correction factor of 0.93). This is also the performance assumed for the third stage of the 11,000-lb supply ship. The space ship could almost entirely be assembled by using the containers and motors of this stage. The tanks are double walled for protection against smaller meteorites (8), since this stage is designed to have space ship features. A total of approximately fifty successful flights should suffice to equip such expedition. This effort, therefore, is of the same order as required for establishing the small observational satellite. The 11,000-lb supply ship can be regarded as adequate for such operations.

The ultimate goal of space flight will always be the interplanetary expedition. Here the requirements increase abruptly, even for the nearest planets. Although astronautical expeditions certainly are still a remote event, contributions to their realization can indirectly be made today by striving toward better understanding of the problems involved and by attempting utmost rationalization of possible solutions.

At least until chemical propellants can be exchanged for something better, space ships are bound to travel along so-called minimum-energy ellipses³ which have tangential contact with the orbits of the two planets involved. These flight paths yield very long travel times. The per capita weight required for food, power, and other provisions for existence becomes very large. Therefore, the problem imposed by sheer weight requirements can be overcome only by strictly limiting the number of participating personnel⁴ and by optimizing the energy requirements for departure and arrival near the respective planets.

In limiting the personnel, it must be realized that in cases of emergency not the number of humans present will count, but the power of the safety devices available. Probably the most harassing psychological stress during such extended voyages (e.g., 2.7 years for Mars) will be not loneliness, but a feeling of helplessness which cannot be dispelled by a large crowd of equally helpless fellow travelers. Therefore, besides utmost reliability, liberal safety provisions (e.g., powerful lifeboat

³ Or orbits which deviate but little from these ellipses.

⁴ By training, also of scientific personnel, for technical and navigational duties in the space ship. This is very feasible, since only the handling and maintenance of the various devices, not the background of their development and manufacture, must be known to all participants.

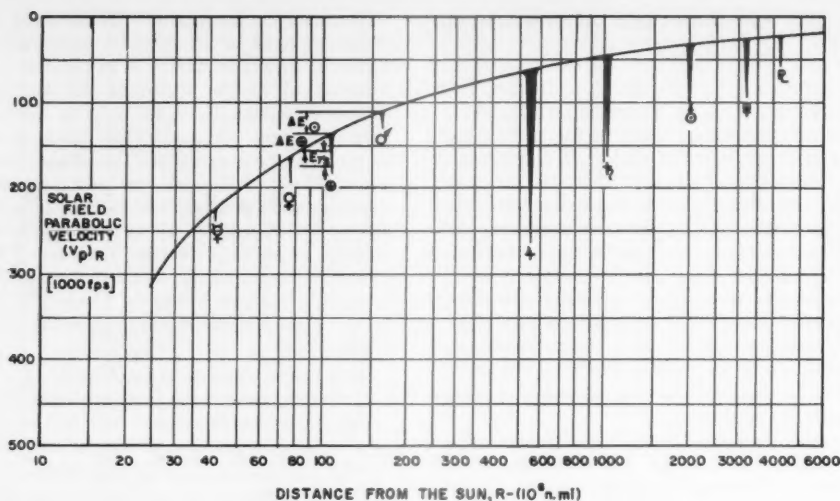


Fig. 3 Gravity field of sun and planets

rockets with equipment for emergency glide landing) for a few persons may very well be more appropriate than employment of a large crew which, for reasons of weight alone, cannot be protected to the same extent.

Of considerable importance is also the correct selection of satellite orbits for departure and arrival. Subsequently, it is demonstrated that optimum orbits exist which reduce the over-all energy requirements to a minimum and save a large amount of supply efforts.

When leaving for another planet, the ships first have to overcome a certain residual portion of the earth's gravity field and, thereafter, a certain portion of the solar gravity field. The first part depends on the distance of the orbit of departure from the earth; the second on the planet to be visited. This is illustrated in Fig. 3, showing the solar field and the superimposed planetary gravity fields as equivalent parabolic velocity, with respect to the sun, versus distance from the sun.

Considering first the solar field only, a body moving from point P to point A (Fig. 4), along a minimum energy ellipse, must possess perihelion velocity at P (perihelion), given by

$$v_P = (v_c)_P \sqrt{\frac{2R_A}{R_P + R_A}} \quad [1]$$

For the sake of simplicity, planetary orbits are considered to be circular. Therefore

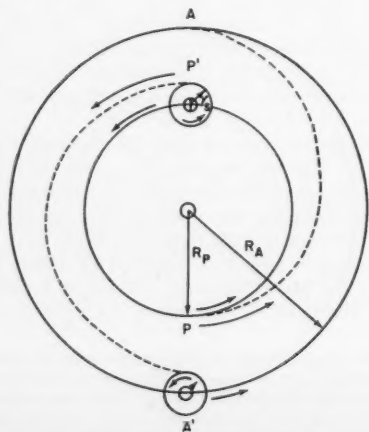


Fig. 4 Interplanetary displacement of a body

$$(v_c)_P = \sqrt{\frac{\gamma_\odot}{R_P}} \quad [2]$$

where

$$\gamma_\odot = g_R R^2 = 2.067 \cdot 10^{10} \left[\frac{\text{n.mi.}^2}{\text{sec}^2} \right] = 1.316 \cdot 10^{11} \left[\frac{\text{km}^2}{\text{sec}^2} \right] \quad [3]$$

If the body has already circular speed in P , its starting velocity with respect to the sun becomes

$$\Delta V_{st} = v_P - (v_c)_P = \sqrt{\frac{\gamma_\odot}{R_P}} \left[\sqrt{\frac{2R_A}{R_P + R_A}} - 1 \right] \quad [4]$$

Actually, the body is within the gravitational field of its home planet. This case is illustrated by the motion from P' to A' in Fig. 4. The body must overcome first the residual gravitational field of its planet, that is, it must attain parabolic speed with respect to this planet, e.g.

$$(v_p)_{r_s} = \sqrt{\frac{2\gamma_\oplus}{r_s}} \quad [5]$$

where

$$\gamma_\oplus = g_{r^2} = 6.254 \cdot 10^4 \left[\frac{\text{n.mi.}^2}{\text{sec}^2} \right] = 3.98 \cdot 10^5 \left[\frac{\text{km}^2}{\text{sec}^2} \right] \quad [6]$$

The starting velocity in A' is then, with respect to the planet,

$$(V_{st})_{r_s} = \sqrt{(v_p)_{r_s}^2 + (\Delta V_{st})^2} \quad [7]$$

The body, being at a distance $r_s > r_{00}$ would possess local circular velocity as satellite of its home planet,

$$(v_c)_{r_s} = \sqrt{\frac{\gamma_\oplus}{r_s}} \quad [8]$$

Therefore, the velocity increment, with respect to the earth, required for moving the body from A' to B' becomes

$$\Delta V_{st} = V_{st} - (v_c)_{r_s} \quad [9]$$

or

$$\Delta V_{st} = \frac{2\gamma_\oplus}{r_s} + \frac{\gamma_\odot}{R_P} \left[\sqrt{\frac{2R_A}{R_P + R_A}} - 1 \right] - \sqrt{\frac{\gamma_\oplus}{r_s}} \quad [10]$$

The energy to be transferred to the body contains the effect of two gravity fields, earth

$$\int_{r_s}^{r=\infty} E dr = \Delta E_\oplus \quad [11]$$

and sun

$$\int_{Y_P}^{R_A} E dR = - \int_{R_A}^{R_P} E dk = |\Delta E_{\odot}| \dots \dots \dots [12]$$

for flights to a target planet outside or inside the earth's orbit, respectively. For a given ΔE_{\odot} , that is, for a given pair of home and target planets, ΔE_{\oplus} varies with the distance r_s . In view of the high energy requirements involved, it is of importance to find the value of r_s for which

$$\frac{\Delta E_{\oplus}}{\Delta E_{\oplus} + \Delta E_{\odot}} = f(r_s) \dots \dots \dots [13]$$

becomes a minimum.

Forming the partial derivative of ΔV_{st} with respect to r_s

$$\frac{\partial(\Delta V_{st})}{\partial r_s} = - \frac{\gamma_{\oplus}}{2r_s^2} \times \left[\frac{2}{\sqrt{\frac{2\gamma_{\oplus}}{r_s} + \frac{\gamma_{\odot}}{R_P}}} \left[\sqrt{\frac{2R_A}{R_P + R_A} - 1} \right]^2 - \frac{1}{\sqrt{\frac{\gamma_{\oplus}}{r_s}}} \right] \dots [14]$$

equating it to zero, and solving for r_s , yields the distance $r_{s, opt}$ of the orbit of departure (or arrival) for which ΔV_{st} becomes a minimum,

$$r_{s, opt} = \frac{2\gamma_{\oplus}}{\frac{\gamma_{\odot}}{R_P} \left[\sqrt{\frac{2R_A}{R_P + R_A} - 1} \right]^2} \dots \dots \dots [15]$$

This relation states the general rule that for optimum distance of departure (or arrival) the energy of the residual planetary gravity field must be equal to the difference in potential energy of the solar gravity field between the two planets contacted. Indeed, Equation [15] can be written in the form

$$\frac{2\gamma_{\oplus}/r_s}{\frac{\gamma_{\odot}}{R_P} \left[\sqrt{\frac{2R_A}{R_P + R_A} - 1} \right]^2} = \frac{\Delta E_{\oplus}}{\Delta E_{\odot}} = 1 \dots \dots \dots [16a]$$

so that the term $f(r_s)$ in Equation [13] becomes 0.5. Therefore

$$(V_{st})_{r_s, opt} = (v_p)_{r_s, opt} \sqrt{2} \dots \dots \dots [16b]$$

Fig. 5 shows the optimum distances with respect to the earth for flights to any planet in the solar system. Obviously, the distance must be infinite for $R_P = R_A$. Large values are obtained for the two neighboring planets, likely to be visited first. With growing distance the solar energy increment increases and, consequently, the optimum satellite orbital distance must decrease. Its theoretical value finally lies inside the earth. This is the case for all trans-Saturnian planets. The variation of the velocity of departure (or of arrival) is plotted against the distance r_s in Fig. 6. The minima are flat, but larger deviations from the optimum distance obviously cause a considerable increase in the required velocity of departure. For Mars flights, for instance, the orbit of departure and arrival usually is assumed at altitudes between 500 and 1000 n.mi. A comparison with the optimum distance shows that the velocity increment can be reduced from 11,000 fps to 7000 fps. At a nozzle exhaust speed of 10,000 fps, for instance, this corresponds to a mass ratio reduction from 3 to 2, if the effect is considered separately from the rest of the journey.

The above rule applies to any planet and to departure as well as arrival, but for our planet it can be applied for arrival only, since for departure, orbital assembly and the related supply system must be taken into account.

The ascending supply ship is subject to three burning periods. In period I it attains circular speed v_I at the distance r_I , usually assumed to be just above the denser portion of the atmosphere,

$$v_I = \sqrt{\frac{\gamma_{\oplus}}{r_I}} \dots \dots \dots [17]$$

Burning period II follows period I immediately or after a short time interval. It provides the necessary velocity increment for entering the transfer ellipse to the satellite orbit at distance r_s

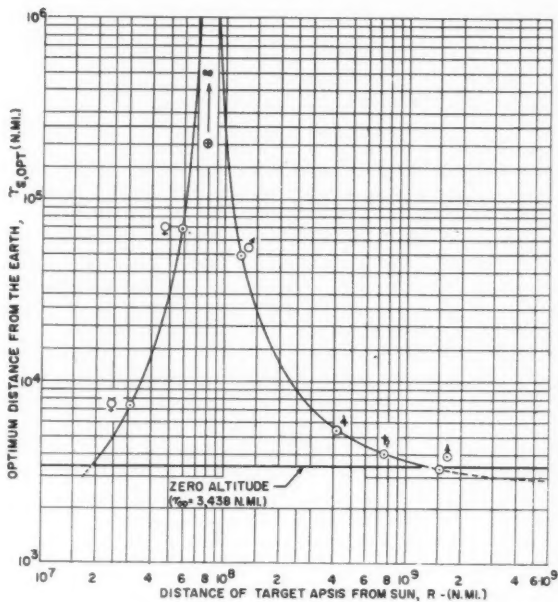


Fig. 5 Optimum distance of departure or arrival as function of the target planet

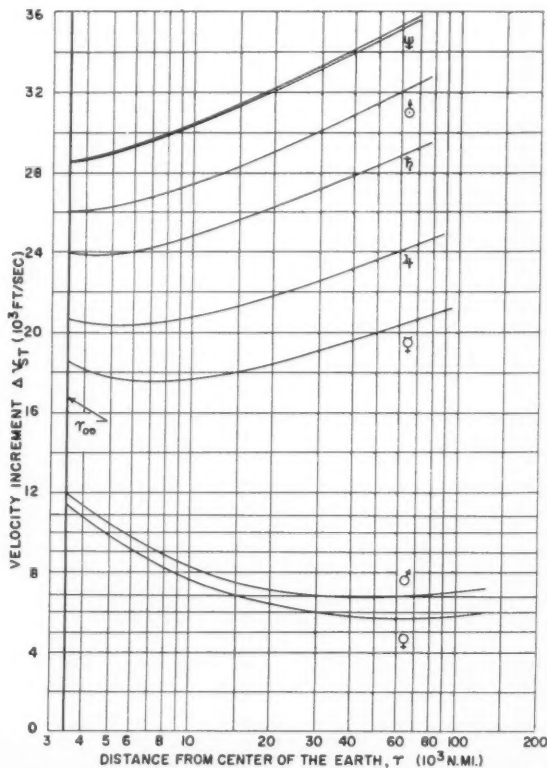


Fig. 6 Velocity of departure vs. distance from earth

$$\Delta v_{II} = v_I \left[\sqrt{\frac{2r_s}{r_I + r_s}} - 1 \right] \dots \dots \dots [18]$$

giving it a perigee velocity of

$$v_P = v_I + \Delta v_{II} \dots \dots \dots [19]$$

The apogee velocity is

$$v_A = v_P \frac{r_I}{r_s} < (v_c)_{r_s} \dots \dots \dots [20]$$

so that a third burning period is required, yielding

$$\Delta v_{III} = (v_c)_{r_s} - v_A \dots \dots \dots [21]$$

The velocity v_I must be attained independently of the distance r_s . It thus remains to investigate the effect of Δv_{II} and Δv_{III} on the selection of an optimum orbit of departure. This has been done, using a Mars flight as example. A typical altitude of about 425,000 ft (130 km) has been selected for h_I and the velocities Δv_{II} , v_A , $(v_c)_{r_s}$, and Δv_{III} plotted as function of the distance r_s in Fig. 7. It can be seen that, while Δv_{II} increases continuously, Δv_{III} reaches a maximum at about 25,000 n.mi. distance. The sum of these two velocity increments shows a maximum at 50,000 n.mi. distance. Adding the values of this curve to the speed-of-departure curve for Mars, plotted again in Fig. 7 for comparison, yields the upper curve which shows that the minimum-energy orbit of departure for all practical purposes lies as close to the surface of the earth as feasible with respect to other requirements (perturbation, for instance). For this reason, the optimum distance, which is about 49,400 n.mi. for Mars, applies only if the space ships alone, but not their assembly and supply, are considered. This can be done, however, in the case of return. Arriving in the far-out orbit saves much propellant which had to be carried through all preceding propulsion periods and which,

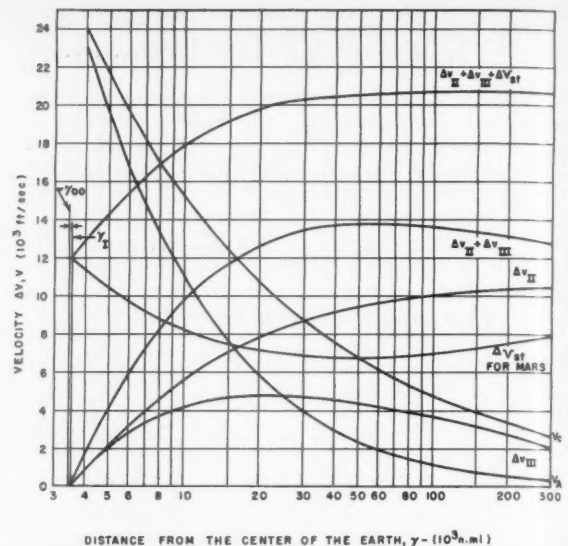


Fig. 7 Effect of supply system on selection of assembly orbit of interplanetary expedition to Mars

therefore, is most expensive. Energy can be saved likewise by applying the same considerations to the target planet. After returning into the optimum satellite orbit, the crew can be picked up by an auxiliary ship, or the space ship is refueled from the earth for descent into a final orbit close to the earth. This freshly supplied energy is considerably less expensive than if it were carried to Mars and back prior to its use.

The economic effect of returning into the optimum satellite orbit is illustrated by considering a Mars expedition as

Table 1 Material Requirements for Mars Expedition

Case		Case 1: Return into orbit of departure				Case 2: Return into optimum orbit			
Orbital altitude (n. mi.)		Departure: 540 Arrival: 540				Departure: 540 Arrival: 46,000			
Propulsion period		A		D		A		D	
Schedule		Lv ⊕	Arr ♂	Lv ♂	Arr ⊕	Lv ⊕	Arr ♂	Lv ♂	Arr ⊕
General performance		Δv (fps)							
A		0.72	0.446	0.446	0.72	0.72	0.446	0.446	0.51
Passenger ship and glider carrier	N	0.1	0.1	0.11	0.125	0.1	0.1	0.11	0.11
	λ	0.18	0.454	0.444	0.155	0.18	0.454	0.444	0.28
Cargo ships	N	0.08	0.08			0.08	0.08		
	λ	0.20	0.474	Abandoned		0.20	0.474	Abandoned	
Passenger ship	W ₀ (1000 lb)	1150	345	244	64			180	36
	W _n	120	35	27	8			20	8
	W _λ	200	156	62&46 ^a	10	Same as 1A	Same as 1A	62&18 ^a	10
	W _p	830	154	109	46			80	18
B-Cargo ship	W ₀ (1000 lb)	800							
	W _n	60							
	W _λ	154		Abandoned		Same as 1A	Abandoned		
	ΔW _λ	6							
	W _p	580							
C-D-Cargo ship	W ₀ (1000 lb)	1770	354			1140	228		
	W _n	142	28			91	18		
	W _λ	354	109&46	Abandoned		228	80&18	Abandoned	
	ΔW _λ	—	13			—	10		
	W _p	1274	158			821	102		
Glider carrier	W ₀ (1000 lb)	2000	369						
	W _n	100	37						
	W _λ	369	160	Abandoned		Same as 1A	Same as 1A	Abandoned	
	ΔW _λ	—	7						
	W _p	1440	164						

^a 46 and 18: propellants needed for prop. period D.

^a 46 and 18: propellants needed for prop. period D.

numerical example (9). The operation involves eight persons, three space ships, and two landing gliders for descent to the surface of planet Mars. The main data are presented in Table 1, based on the following assumptions:

(a) The passenger ship alone returns to the earth and therefore has four propulsion periods, labeled A through D. The two other vehicles are cargo ships, carrying propellants for the respective propulsion periods of the passenger ship. They are designated accordingly.

(b) The passenger ship departs, filled with propellant for period A only. Prior to arrival near Mars it is filled for period B by the B-cargo ship which subsequently is abandoned.

(c) At the end of the stay time near Mars (about 450 days) the payload is so much decreased that the passenger ship can take over the propellants for both residual periods, C and D, from the C-D-cargo ship which is left behind as satellite of Mars.

(d) Each landing glider, having a total weight of 160,000 lb, is transported by a glider carrier. In fact, these are two additional space ships with a payload of 160,000 lb each. They are also left behind in the Mars orbit.

(e) Each of the cargo ships has an additional payload, ΔW_λ of the quantity indicated in Table 1. It consists of reserve parts and reserve propellants.

(f) An initial payload of 200,000 lb was computed, tentatively, for the passenger ship. This amounts to an average of 25,000 lb per person over a period of about 1000 days.

(g) The motor performance is based on nitric acid (RFNA) and hydrazine, $I_{sp} = 305$ sec; expansion ratio 590 to 1.47 psia; $r = 1.38$.

(h) The space ships are equipped with a number of small motors and so designed that power plants and structure can be abandoned prior to each propulsion period, following the first one, in proportion to the propellant and payload consumed since the preceding period. Thereby the mass which must be accelerated is always a minimum.

(i) Distance of the Mars satellite orbit is equal to that of the moon Phobos for reasons in connection with the study. The optimum distance would lie inside Mars, 540 n.mi. from its center.

(j) The orbit of departure was assumed at 540 n.mi. altitude.

In Table 1, return into the orbit of departure is compared with arrival at optimum altitude. The resulting over-all requirements are summarized in Table 2. In comparing these values with those in Table 1, it must be remembered that the values for the glider carrier count twice. The ratio of the

responds to 74 ascents of the 11,000-lb supply ship exceeding by a substantial margin the over-all efforts for the small satellite or a circumnavigation of the moon.

If the Mars satellite orbit is placed as close to the surface as possible, even more could be saved. Moreover, the landing gliders would become smaller, since they need less propellant for return from the surface.

The remaining material requirement of about 6.8 million pounds nevertheless is formidable. The propellant alone requires about 530 supply flights with the large ship. The total number will come close to 600 flights, even if one assumes that some material of the third stage can be used for construction of the space ships. Still, this may not yet warrant the additional efforts of designing and developing a larger supply ship, particularly, since such expedition probably will be a singular event.

The preceding discussion, therefore, suggests three prototypes of earth-to-orbit vehicles: a light supply ship for regular maintenance flights, a passenger ship, and a heavy supply ship for periods of increased supply demand. Payloads of 2000 lb and 11,000 lb, respectively, for these three vehicles were found to be a reasonable tentative base for the establishment of a small, inhabited satellite of 200,000 cu ft volume, as well as for space flight on a moderate scale.

References

- 1 "Wege zur Raumschiffahrt (Ways and Means for Space Flight)," by Herman Oberth, Publ. R. Oldenbourg, Berlin, 3rd edition, 1929, pp. 351-371.
- 2 "Die Rakete" (The Rocket), *Journal of the Verein fuer Raumschiffahrt*, Breslau, 1927-1929. See also: "Guido von Pirquet," *Journal of the British Interplanetary Society*, vol. 9, No. 4, July 1950, pp. 205-206.
- 3 "The Establishment of Large Satellites by Means of Small Orbital Carriers," by K. A. Ehricke, AMERICAN ROCKET SOCIETY Paper No. 69-52, December 1952.
- 4 "Results of Observations of Meteor Trains in Jadikistan (1934-1938)," by V. V. Fedynsky, *Astr. J. Sov. Un.*, vol. 21, 1944, pp. 291-306.
- 5 "Long Enduring Meteor Trains," Second Paper, by C. P. Olivier, *Proc. Amer. Phil. Soc.*, vol. 91, 1947, pp. 315-327.
- 6 "Meteorology: The Exploration of the Upper Atmosphere," by P. A. Sheppard, *Sci. Progr.*, vol. 37, 1949, pp. 408-503.
- 7 "A Rocket Drive for Long-Range Bombers," by Eugen Sanger and Irene Bredt, *Deutsche Luftfahrtforschung*, LLM 3538, 1944, transl. by M. Hamermesh; Reprod. R. Cornog, 990 Cheltenham Road, Santa Barbara, Calif.
- 8 "Meteoritic Phenomena and Meteorites," by Fred L. Whipple, Contributions to Physics and Medicine of the Upper Atmosphere, Clayton S. White and Otis O. Benson, ed., The University of New Mexico Press, Albuquerque, 1952, 1st edition, pp. 137-170.
9. Based on an unpublished study, "Expedition Ares," by K. A. Ehricke, Ft. Bliss, 1948.
- 10 "Weight-Strength Analysis of Aircraft Structures," by F. R. Shanley, The RAND Corporation, McGraw-Hill Book Company, Inc., New York, 1st edition, 1952.
- 11 "Vision at High Speed and Altitude," by Col. Victor A. Byrnes, *Aeronautical Engineering Review*, vol. 12, no. 4, April 1953, p. 60.
- 12 "I Fondamenti del' Astronautica (On the Fundamentals of Astronautics)," by G. Arturo Crocco, *L'Aerotecnica*, April 1953, p. 135. Listed in the Aeronautical Reviews of the *Aeronautical Engineering Review*, vol. 12, no. 9, September 1953, p. 124.
- 13 "The Mars Project," by W. Von Braun, University of Illinois Press, Urbana, Ill., 1953.

(End of Part 1.) Part 2 will appear in the next issue of JET PROPULSION.

Table 2 Summary of Material Requirements for Mars Expedition

	Arrival at orbit of departure	Arrival at optimum orbit
ΣW_λ (lb)	520,000	520,000
$\Sigma \Delta W_\lambda$ (lb)	33,000	30,000
ΣW_n (lb)	522,000	471,000
ΣW_p (lb)	6,610,000	5,793,000
Total	7,685,000	6,814,000

Difference:

W_p 817,000
 W_n 51,000
 ΔW_λ 3,000

Total weight saved (lb) 871,000

total requirements of case 2 over case 1 is about 0.89, the difference amounting to 871,000 lb. The propellant alone cor-

Unconditional Stability of Low-Frequency Oscillation in Liquid Rockets

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The minimum value n_{\min} of the interaction index compatible with unstable oscillations in a liquid rocket is advanced as the basic criterion of unconditional stability of the system. For systems with known constants of the feeding system components, the value of n_{\min} is given explicitly in terms of these constants. For any arbitrary system for which the constants of the feeding system components are not easily evaluated, the value of n_{\min} of such systems can be obtained directly from certain flow tests of the over-all feeding system. If the interaction index n of the propellant is less than this n_{\min} , the system is unconditionally stable regardless of the magnitude of the time lag of the system. Any change in the design of the feeding system of certain component constant leading to a larger n_{\min} is stabilizing. The effects of several constants are briefly discussed. In particular, the transfer function of the feedback circuit of a servomechanism actuating a control capacitance next to the injector that will make a given system unconditionally stable is given explicitly in terms of these constants for both monopropellant and bipropellant systems.

Introduction

THE stability of low-frequency oscillations in liquid rocket motor has been analyzed by many authors. Under several simplifying assumptions, the course of variation of a pressure disturbance in the combustion chamber is governed only by the consideration of mass balance. So far, the most complete formulation is due to Crocco (1)² and is given in dimensionless form as

$$\frac{d\varphi(z)}{dz} + \varphi(z) = N \cdot \varphi(z - \delta_i) + n \cdot [\varphi(z) - \varphi(z - \delta)] \quad (1)$$

where $\varphi(z)$ is the fractional chamber pressure variation at the instant z , which is the reduced time based upon the gas residence time including the effect of the nozzle (2). The two terms on the left-hand side represent respectively the variations of the rates of accumulation of mass in the chamber and of the ejection of mass out of the chamber. The two terms on the right-hand side represent the variations of the rates of burned gas generation through the variation of injection rate $N \cdot \varphi(z - \delta_i)$ and the variation of the specific rate of conversion of unburned propellants in the chamber into burned gas. N is the ratio of the fractional variation of injection rate μ_i to the fractional variation of chamber pressure φ at any instant and may be called the transfer function of the feeding system. n is the index of interaction between the specific rate of burned gas generation (burning rate) and the different physical factors affecting the rate of combustion processes expressed in terms of the instantaneous gas pressure (1). δ_i is the reduced total time lag that elapses after the propellant is

injected into the chamber before it burns. The part δ_i of the total time lag is insensitive to variations of physical properties in the chamber, and the other part $\delta = \delta_i - \delta_i$ is sensitive. For systems in which the mixing pattern or flame-holding characteristics are not essentially modified by the pressure oscillations, the interaction index n is expected to be basically a property of the propellant and can be determined experimentally. A propellant with larger n is more liable to exhibit unstable phenomenon.

The transfer function N of the feeding system depends upon a number of parameters and is a function of the frequency of oscillation. In an attempt to formulate it analytically, the complicated feeding system is usually represented

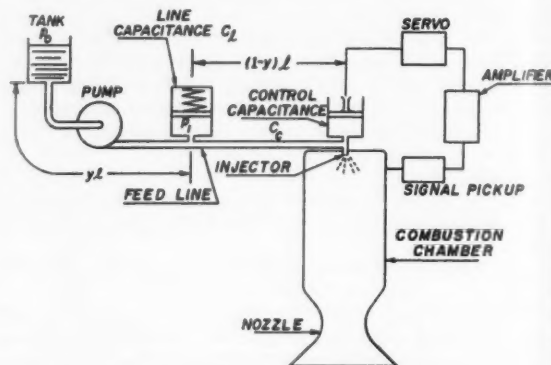


Fig. 1 Schematic liquid rocket system

schematically as shown in Fig. 1, with feed line of uniform section and with single concentrated capacitance, etc. The transfer function N for such a system can be obtained as

$$N \left(\frac{d}{dz} \right) = \frac{\mu_i}{\varphi} = - \left[\frac{A}{B} + \frac{C}{B} \frac{d}{dz} F \left(\frac{d}{dz} \right) \right] \quad (2)$$

with

$$\begin{aligned} A &= P \left[1 + DE \left(P + \frac{1}{2} \right) \frac{d}{dz} + JEy \frac{d^2}{dz^2} \right] \\ B &= 1 + D \left(P + \frac{1}{2} \right) + \left[DE \left(P + \frac{1}{2} \right) + J \right] \frac{d}{dz} + \\ &\quad \left[DJE(1-y) \left(P + \frac{1}{2} \right) + JEy \right] \frac{d^2}{dz^2} + J^2 E y (1-y) \frac{d^3}{dz^3} \\ C &= D \left(P + \frac{1}{2} \right) + J \frac{d}{dz} + DJE(1-y) \left(P + \frac{1}{2} \right) \frac{d^2}{dz^2} + \\ &\quad J^2 E y (1-y) \frac{d^3}{dz^3} \end{aligned}$$

where $P = p/2\Delta p$ is the ratio of chamber pressure to twice the pressure drop across the feeding system, $D = -\frac{\Delta p}{p} \frac{\Delta \dot{m}}{\dot{m}}$ is the negative of the ratio of the fractional variation of pump

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² Numbers in parentheses refer to References on page 315.

delivery pressure to that of mass delivery rate. $J = \frac{l\dot{m}}{2\Delta p A_s \theta g}$ is the inertia parameter of the feed line and $E = \frac{2\Delta p \rho \alpha x / \dot{m} \theta g}{2\Delta p \rho \alpha x / \dot{m} \theta g}$ is the elasticity parameter of the feed line represented by an equivalent concentrated capacitance of spring constant x located at a distance $y-l$ downstream of the pump delivery. $F(d/dz)$ is the transfer function of the feed back servo-control circuit as was introduced by Tsien (3).

A Practical Criterion for Unconditional Stability

It is clear from Equations [1] and [2] that the algebraic manipulations involved with the general form of this transfer function N are prohibitively heavy. As a result, only a few simple systems and several specific examples have been investigated (1, 3-8) and few criteria have been deduced to guide the design of the feeding system for a stable rocket except that larger pressure drop Δp across the feeding system is likely to give a more stable rocket.

The practical value of an accurate determination of the stability boundary is limited because few of the parameters are known with any degree of accuracy except P and probably D . This fact has long been noticed, especially concerning the magnitude of the time lag that the ultimate object of a stable design is to have the system stable for all values of the time lag; that is, "unconditionally stable." Summerfield (6) showed that if $n = 0$, $P < 1$ or $\Delta p > p/2$ is sufficient to guarantee unconditional stability of a constant pressure feed system. Crocco (1) generalized this to arbitrary n , i.e., $P < 1 - 2n$ for both constant rate and constant pressure system. Crocco's result immediately shows that unconditional stability is not possible if $n > 1/2$; that is, when the mechanism through the variation of the specific rate of combustion alone is capable of exciting instability (intrinsic instability). Tsien (3) has formulated a graphical criterion of unconditional stability for a general system—that the Satche diagram of the system must not intersect the unit circle. However, it is difficult to use this criterion in practical design because we do not know all the feeding system constants in the schematic representation, even if it is appropriate.

Let us now look at the problem from a slightly different point of view. The transfer function $N(d/dz)$ of a given feed system is well defined. If the pressure of the gas in a tank is made to oscillate at a frequency ω , the transfer function $N(i\omega)$ of the feed system injecting fuel into the tank without combustion can be determined experimentally. The problem of measuring instantaneous flow rate can be solved. If this is known, the stability behavior of the rocket using a given propellant can be determined: Let us denote

$$N(i\omega) = N_r(\omega^2) + i\omega N_t(\omega^2) \dots \dots \dots [3]$$

We shall inquire what amount of excitation due to the variation of specific burning rate will be required to maintain neutral oscillations of different frequencies ω . For a given feed system, there will be a particular frequency of neutral oscillation which requires the minimum amount of excitation from n . We call this n_{\min} , which is a characteristic property of the given feed system. If such a feed system is used with a propellant whose n is less than this n_{\min} , no neutral oscillation is possible and the system is unconditionally stable. A stable design of the feed system is therefore characterized by a large value of n_{\min} . Any change in the design of the feed system which leads to a larger n_{\min} is favored in the design for unconditional stability.

Put $\varphi(z) = \exp(i\omega z)$ in Equation [1] and separate the real and the imaginary parts to obtain two real equations and denote

$$R + iS = N(i\omega) \cdot e^{-i\omega \delta} \dots \dots \dots [4]$$

Then the elimination of δ from the two real equations gives

$$n_* = \frac{1}{2} \frac{1 + \omega^2 - (R^2 + S^2)}{1 - R} \dots \dots \dots [5]$$

Let us first consider the case where $\delta_i = 0$; that is, all time lag is sensitive. This is the only case which has been considered by previous authors with $n \neq 0$. For this case

$$R = N_r(\omega^2); \quad S = \omega N_t(\omega^2) \dots \dots \dots [6]$$

which are known functions of ω . Then n_* can be plotted for different values of frequency ω of neutral oscillations and a minimum can be found to occur at some value ω_0 corresponding to n_{\min} . This minimum value can be determined without considering any other parts of the rocket and without a single firing. By adjusting the feeding system constants or by using feedback servo control, if necessary, the feed system can be designed to give unconditional stability for given value of n of the propellant.

Equation [2] can be used to obtain some valuable qualitative information for the design of unconditional stability. For systems without servo stabilization, we have

$$N_r(\omega^2) = -P \{ [1 + D(P + 1/2)] + \omega^2 [D^2 E^2 (P + 1/2)^2 - 2J E y] + \omega^4 J^2 E y (1 - y) \} / \Delta^2$$

$$N_t(\omega^2) = P \{ [J - D^2 E (P + 1/2)^2] + \omega^2 [D^2 E^2 J (P + 1/2)^2 (1 - y) - J^2 E y (2 - y)] + \omega^4 J^2 E^2 y^2 (1 - y) \} / \Delta^2$$

with

$$\Delta^2 = \{ [1 + D(P + 1/2)] - \omega^2 [D J E (1 - y) (P + 1/2) + J E y] \}^2 + \omega^2 \{ [D E (P + 1/2) + J] - \omega^2 J^2 E y (1 - y) \}^2 \dots [7]$$

For low-frequency oscillations (or chugging), ω is not considerably larger than unity. The nature of the curve $n_*(\omega)$ at small ω is therefore of particular interest. It is easy to see from Equations [5] and [7] that $(dn_*/d\omega)_{\omega=0} = 0$ and $n_*(0)$ is an extreme value which is always less than $1/2$.

$$n_*(0) = \frac{1 + N_r(0)}{2} = \frac{1}{2} \left[1 - \frac{P}{1 + D(P + 1/2)} \right] < \frac{1}{2} \dots [8]$$

Here $N_r(0) = -P/[1 + D(P + 1/2)]$ is the ratio of the fractional variation of the injection rate to that of chamber pressure when the steady-state chamber pressure is changed to a new level. Equation [8] shows that for sufficiently large P (small Δp across feed system) and small D , $n_*(0)$ and therefore n_{\min} are both less than zero. This means that the pressure sensitivity of the feed system alone is capable of exciting instability and the system cannot be unconditionally stable without servo control.

It can be shown that when $D = 0$ or $E = 0$, $n_*(0)$ is a minimum; but when $D = \infty$, $N_r(0)$ is a maximum. An extensive discussion of this point is not very fruitful, neither is it helpful because, for given value of D , it depends very much on the relative magnitude of E , J , and y which are little known. As a general trend, $n_*(0)$ is a minimum for systems with small D and/or E . For such cases, $n_*(0) = n_{\min}$ because both $N_r(\omega)$ and $N_t(\omega)$ become small at large ω , and $n_*(\infty)$ will increase as $(1 + \omega^2)/2$. For systems with centrifugal pump $D \cong 1$, it is found that smaller E and larger J tend to make $n_*(0)$ a minimum and vice versa, and the relative magnitude of E and J is also important. Since both E and J cannot be easily known with accuracy, a reliable value of n_{\min} is best obtained from the experimentally determined values of $N_r(\omega^2)$ and $N_t(\omega^2)$. Unconditional stability can be obtained with the given feed system only when the value of n of the propellant used in the rocket is smaller or, at most, equal to this n_{\min} .

Cases Requiring Servo Stabilization

(a) Small Units

It is apparent that for systems not servo-controlled, unconditional stability is not possible if n of the propellant is

bigger than $n_*(0)$ which is always less than $1/2$. If it is desired to obtain unconditional stability in this case, servo-control would be necessary. Let us consider first systems with small D or E for which $n_*(0) = n_{\min}$. This is the case for most small thrust units which employ compressed gas feed. It is simple to show from Equations [3], [6], and [7] that to obtain unconditional stability the transfer function of the feedback circuit

$$\left. \begin{aligned} F(s) &= (f/s)[1 + a_1s + a_2s^2 + a_3s^3 + \dots] \quad \text{for } D \neq 0 \\ \text{and} \\ F(s) &= (f/s^2)[1 + b_1s + b_2s^2 + b_3s^3 + \dots] \quad \text{for } D = 0 \end{aligned} \right\} \dots [9]$$

must satisfy the following power requirement if the interaction index of the propellant is n

$$\left. \begin{aligned} -f &\geq \frac{P + 2n - 1}{D(P + 1/2)} + 2n - 1 \quad \text{for } D \neq 0 \\ \text{or} \\ -f &\geq (P + 2n - 1)/J \quad \text{for } D = 0 \end{aligned} \right\} \dots [10]$$

The coefficients a'_s or b'_s characterizing the shape of the transfer function are relatively unimportant in this case and can be selected to give a more positive $(d^2n_*/d\omega^2)_{\omega=0}$ or, for convenience, to leave $(d^2n_*/d\omega^2)_{\omega=0}$ unchanged. For the latter case

$$\left. \begin{aligned} \{a_1 &= -J/D(P + 1/2) \\ a_2 &= J^2/D^2(P + 1/2)^2 - JE(1 - y) \quad \text{for } D \neq 0 \\ \text{and} \\ \{b_1 &= 0 \\ b_2 &= -JEy(1 - y) \quad \text{for } D = 0 \end{aligned} \right\} \dots [11]$$

The stabilization is accomplished by the feedback servo in adding a sufficiently large positive contribution to $N_r(0)$ so that $n_{\min} \cong n_*(0)$ is shifted to larger values, larger than n of the propellant. The feedback circuit can of course be cut out at large ω by replacing the power series portion of $F(s)$ with the ratio of two polynomials whose denominator is of higher degree. Marble (9) suggested the following form

$$F(s) = \frac{f}{s} \frac{1 + a_1s}{[1 - a_2s^2/2]^2} \dots [12]$$

from a different reasoning. The present results indicate, however, that the form of the transfer function given as Equation [12] is sufficient only for systems with small D or E where n_{\min} is given by $n_*(0)$ (Marble's consideration is for $E = 0$ only). For systems with neither D nor E small, as most of the large thrust units are likely to be, n_{\min} can be considerably smaller than $n_*(0)$ so that Equations [9], [10], and [11] cannot be relied upon for the design of the feedback circuit with a view to unconditional stability.

(b) Large Units

For large thrust units which usually employ centrifugal pumps, D is of the order of unity and E is not small. Then, the value of n_{\min} should better be determined from experimental values of $N(i\omega)$. If it should turn out $n_*(0) = n_{\min}$ or very nearly so with $\omega_0 \cong 0$, Equations [9], [10], and [11] could of course be used in designing the feedback circuit. If n_{\min} occurs at ω_0 different from 0, then the transfer function $F(s)$ should be selected to be most effective near ω_0 . This can be accomplished by selecting $F(s)$ in such a way as to contribute a sufficiently large positive value to $N_r(\omega_0)$ but leave $N_s(\omega_0)$ unchanged. Thus

$$F(s) = \frac{-f}{s} \left[\frac{C(-s)}{B(-s)} \right] \dots [13]$$

where $C(-s)$ and $B(-s)$ are the two polynomials obtained from Equations [2] by replacing d/dz with $-s$. The coefficient f must satisfy the following requirement to obtain unconditional stability with a propellant having an interaction index n

$$-f \geq 2(n - n_{\min}) \left| \frac{B(i\omega_0)}{C(i\omega_0)} \right|^2 \dots [14]$$

Since the coefficients of both $B(s)$ and $C(s)$ involve not only P , D , but also E , J , and y , the question naturally arises how to determine the coefficients of $B(s)$ and $C(s)$ in designing the feedback circuit. With the transfer function $N(d/dz) = -A(d/dz)/B(d/dz)$ for the feed system without servo control experimentally determined, it is only a simple algebra to determine E , J , and y . Knowing E , J , and y , one can obtain the functions $B(s)$ and $C(s)$ as defined in Equations [2]. The uncertainty of the schematic representation of the feed system makes it necessary that the values of E , J , and y be so determined as to be representative near the frequency ω_0 .

Extension to Bipropellant Case

The above discussions and results can be easily generalized to bipropellant motor if $N_r(\omega^2)$ and $N_f(\omega^2)$ are defined as

$$\left. \begin{aligned} N_r &= N_{ro} \cdot (1/2 - 2K + H) + N_{rf} \cdot (1/2 + 2K - H) + \\ &\quad (N_{ro} - N_{rf})3K \cos \omega + (N_{io} - N_{if})3K \omega \sin \omega \\ N_f &= N_{fo} \cdot (1/2 - 2K + H) + N_{ff} \cdot (1/2 + 2K - H) - \\ &\quad (N_{ro} - N_{rf})3K \sin \omega/\omega + (N_{io} + N_{if})3K \cos \omega \end{aligned} \right\} \dots [15]$$

where subscripts o and f denote the quantity pertaining to the oxidizer and the fuel system, respectively. The quantities K and H are defined by Crocco (1) in terms of the mixture ratio $\bar{r} = \bar{m}_{io}/\bar{m}_{if}$ in steady state as

$$H = \frac{1}{2} \cdot \frac{\bar{r} - 1}{\bar{r} + 1} \quad K = \frac{1}{2} \cdot \frac{\bar{r}}{T_g} \cdot \frac{dT_g}{d\bar{r}} \dots [16]$$

Of course, in the bipropellant case both the transfer functions $N_o(i\omega)$ and $N_f(i\omega)$ must be determined experimentally.

For the bipropellant case, Equation [8] becomes

$$\left. \begin{aligned} n_*(0) &= \frac{1 + N_r(0)}{2} = \\ &= \frac{1}{2} \left[1 - \frac{P_o(1/2 + K + H)}{1 + D_o(P_o + 1/2)} - \frac{P_f(1/2 - K - H)}{1 + D_f(P_f + 1/2)} \right] < \frac{1}{2} \dots [17] \end{aligned} \right\}$$

Equations [10], when only the oxidizer system is controlled, become

$$\left. \begin{aligned} -f_0 &\geq \left[2n - 1 + \frac{P_o(1/2 + K + H)}{1 + D_o(P_o + 1/2)} + \frac{P_f(1/2 - K - H)}{1 + D_f(P_f + 1/2)} \right] \times \\ &\quad \frac{1 + D_o(P_o + 1/2)}{D_o(P_o + 1/2)} \cdot \frac{1}{1/2 + K + H} \quad (D_o \neq 0) \\ -f_0 &\geq \left[2n - 1 + P_o(1/2 + K + H) + \frac{P_f(1/2 - K - H)}{1 + D_f(P_f + 1/2)} \right] \times \\ &\quad \frac{1}{J_o(1/2 + K + H)} \quad (D_o = 0) \dots [18] \end{aligned} \right\}$$

For the general case with $\omega_0 \neq 0$, when only the oxidizer system is controlled, Equations [13] and [14] become

$$F_0(s) = -\frac{f_0}{s} \left[3K e^{i\omega_0} + \frac{1}{2} + H - 2K \right] \cdot \left[\frac{C(-s)}{B(-s)} \right] \dots [19]$$

with

$$-f_0 > 2(n - n_{\min}) \cdot \left| \frac{B(i\omega_0)}{C(i\omega_0)} \right|^2 / |3K e^{i\omega_0} + 1/2 + H - 2K|^2 \dots [20]$$

If only the fuel system is controlled, similar expressions can be obtained from Equations [17] to [20] simply by interchanging subscripts o and f and changing K and H to $-K$ and $-H$.

(Continued on page 315)

The Crucial Problem in Astronautics: Recovery of Multistage Vehicles

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From long experience in practical aeronautical development, the author argues the advantages of a cautious step-by-step program of developing and proof-testing multistage orbital vehicles. In his view, each stage must be a complete flying machine capable of ascending into space and returning safely to earth. This paper, the first of two on the aerodynamic and mechanical problems of multistage rockets, deals with the problem of high-speed descent through the atmosphere and suggests means of avoiding destructively high temperatures.

Nomenclature

V	= speed, m/sec
ρ	= absolute air density
ρ_0	= ground air density
Z	= altitude, km
H	= const, km
i	= $\rho/\rho_0 \cong e^{-Z/H}$
W	= dry weight of tank
Ω	= cross section of body
B	= $W/\rho_0\Omega$ = ballistic factor, m/sec ²
L	= total lift of tank
D	= total drag of tank
C_L	= lift coefficient = $L/\rho V^2$
ϕ	= angle of attack of body
K_L	= C_L/ϕ = lifting power
C_D	= drag coefficient for $\phi = D(\phi=0)/\rho V^2$
β	= slope of descent
t, s	= time; range, km
Z_0	= initial altitude
V_0	= initial speed; V_1 = landing speed
β_0	= initial slope = 0
σ/g	= physiological bearing = $\sqrt{(D/W)^2 + (L/W)^2}$

FOR the planning of a practical program of extraterrestrial flight, I wish to stress two considerations, each born of a long personal experience in aeronautical developments. The first is that the achievement of the escape velocity through multistage rocket-powered vehicles will surely be delayed by many costly failures if it is attempted all in one step, as some popular writers have proposed in recent years. The soundest basis for development is a careful step-by-step program of making, at first short-range, then longer-range terrestrial flights, and finally orbital flights. The second consideration, from the standpoint of economics, is that each stage of a multistage escape rocket must be capable of flying safely back to the surface of the earth and eventually to the launching base for re-use, unless large sums of money are to be squandered recklessly.

Both of these considerations point to the desirability of designing each stage of a multistage rocket as a self-contained, streamlined, aerodynamically stable and controllable aircraft. The first phase of the development program, as I conceive it, would be to construct and perfect the last stage (the smallest one) and subject it to rigorous flight tests as a supersonic airplane on a ballistic-type trajectory of modest range. When this has been accomplished, the next-to-last stage then can be developed and tested, first as an airplane by itself, then

as a launcher for the previously developed smallest stage. Step-by-step, the ultimate multistage escape rocket can be developed in this way quite logically and with a maximum chance for success.

This line of thought immediately raises technical questions concerning the aerodynamic design of the respective stages and the mechanical assembly of a multistage rocket of these characteristics. These questions will be discussed in detail in a sequel to this paper. Another technical question concerns the problem of the descent from a high velocity trajectory outside the atmosphere down to the surface of the earth. In this paper I treat the aerodynamics and thermal aspects of the descent of an intermediate stage. (Let us call such a stage a "tanker," since that describes quite well its main function.)

The descent of the tanker will take place mostly in the supersonic speed range. This is fortunate from a computational standpoint since it allows simple approximations for the aerodynamic forces, which are adequate for an exploratory investigation of this type.

The symbols used in the approximations are listed in the nomenclature. As one can see, the relative density, δ , is assumed to be given by $\exp(-Z/H)$ where Z is the altitude in kilometers and H is a constant altitude of 7.2 kilometers.

The drag coefficient, C_D , and the lift coefficient, C_L , are here referred to the master section of the body, Ω , and to the square of the indicated velocity, δV^2 , instead of its half as used in aerodynamics. Moreover, we have called the lifting power the ratio, K_L , obtained by the division of the coefficient C_L through the angle of incidence taken with respect to the axis of the body.

As a reasonable approximation we shall suppose that the lift closely compensates the empty weight, W , though it differs from it in the amount needed to entertain the curvature of the trajectory during the maneuver of the descent. Moreover, we shall assume that both C_D and K_L are constant; the first as a suitable mean value for the complete supersonic range down to Mach 1 or 2; and the second on the grounds of the following considerations. We suppose a continuous manual or automatic intervention to correct the lift of the tanker for its dependency on Mach number through the joint use of the tail elevator and head elevator controlled in such a way as to obtain the necessary incidence, at the same time making the lifting power K_L constant. This computational artifice reduces considerably the lifting power which can be obtained, but it is very useful also for the simplicity of the algebra. This is shown by the formulations in Table 1 which can be applied to the case where the indicated velocity $V\sqrt{\delta}$ is maintained constant in the descent. The indicated velocity is chosen at its optimum value which makes the passive drag equal to the induced drag² and, due to the constant C_D and K_L , results in a constant minimum value for the ratio D/W between the drag and the weight. There follows with the introduction of the exponential expression for δ , the simple formulations for the slope down, β , and for the duration of the trajectory and the range which results in a maximum. The trajectory is drawn in Fig. 3 with the title of *optimum descent*, to-

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¹ Professor Emeritus.

² This concept has been introduced by the author (Ref. 1) in 1932.

Table 1

$$D = (C_D + K_L \phi^2) \rho \Omega V^2$$

$$\frac{D}{W} = \frac{(C_D + K_L \phi^2) \delta V^2}{B}$$

$$\frac{D}{W} = \text{optimum} = 2 \sqrt{\frac{C_D}{K_L}} = 2 \phi$$

$$(\delta V^2)_{\text{opt}} = \text{const} = \frac{B}{\sqrt{C_D \cdot K_L}}$$

$$d(\delta V^2)_{\text{opt}} = d(V^2 e^{-z/H}) = 0$$

$$\frac{dV}{V} = \frac{dZ}{2H} = \text{optimum descent law}$$

$$(\sin \beta)_{\text{opt}} = \frac{-(D/W)_{\text{opt}}}{1 + (V^2/2gH)}$$

$$\left(\frac{D}{Q}\right) \cong \frac{V_0 - V_1}{g} + \frac{2H}{V_1} - \frac{2H}{V_0}$$

$$\left(\frac{D}{Q}\right) \cong \frac{V_0^2 - V_1^2}{2g} + Z_0$$

gether with a different type of trajectory that we are going to illustrate and which has been called minimum range.

First it is necessary, however, to discuss, though briefly, the problem of the temperature; that is, the heating caused by the friction of the air at the elevated velocities. This problem has an interesting history inasmuch as it has been indicated in fluid dynamics in 1928 (2)² and was soon thereafter solved (3, 4)² with the proposal of the subtraction of heat from the boundary layer through a suitable fluid. It is precisely this solution which is indicated and treated today by numerous researchers and which transfers the problem from the field of aviation, where it was born, to the field of astronautics where one is concerned with the temperature barrier at high velocities.

I will follow in this regard the figures presented in a paper by Klunker (5) for the case of a nonlifting plate. We will obtain from these figures the order of magnitude of the phenomenon.

For the purpose of the discussion I take the Mach number equal to 10. At this velocity the pure stagnation temperature results in a temperature of 8600 R. This reduces to 2400 R if only we take into account the radiation in space following the Stephen-Boltzmann law at sea level, sun absent. But, if one rises to 30 kilometers altitude, this equilibrium temperature reduces in the same condition of radiation to only 830 R, that is, 185 C above the ice point. At 60 kilometers altitude one would find the same temperature as in a lecture room during the summer. All this with no other heat subtraction but natural radiation. In other words, there is always an altitude at which, no matter how large the Mach number is, the natural radiation is sufficient to reduce the equilibrium temperature to any prescribed value.

However, in these terms the question is purely academic. We wish now to insert it in the problem of the descent in the atmosphere as it has been delineated before. The result is represented in Fig. 1. First of all I have chosen the temperature of 1000 R (280 C) as a reasonable maximum compatible with the material of the tanker. In the ordinates the altitudes considered by Klunker have been traced; that is, roughly, 45, 30, 15, and 0 km; and in the abscissa the corresponding Mach number obtained by graphical interpolation for the temperature of 1000 R. We obtain in this way a surprisingly linear relationship between Mach number and altitude. This relationship is indicated in the figure as the constant temperature law. It starts at Mach 5 at sea level and increases up to Mach

² Numbers in parentheses refer to References on page 315.

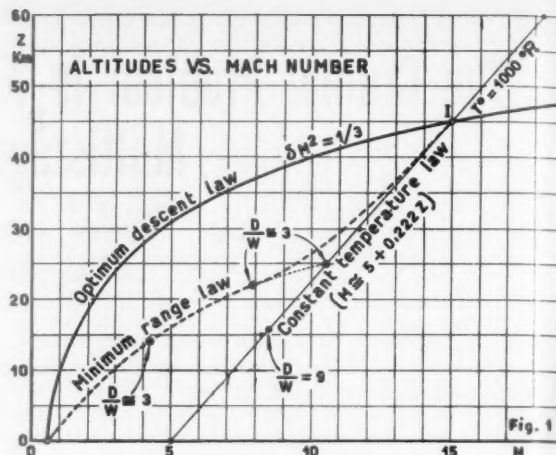


Fig. 1 Altitude vs. Mach number

15 at 45 km altitude; it has been extrapolated moreover with the same slope up to 60 km altitude. In comparison with this thermal law we have traced the dynamic law previously recorded by the optimum descent and distinguished by the condition $\delta M^2 = 1/3$. We see that this law has nearly a parabolic behavior from Mach 0.6 at sea level to Mach 15 at 45,000 km, where it intersects the straight line of the constant temperature law. One concludes that the optimum descent up to Mach 15 remains completely in a field of a temperature substantially below 1000 R. Above Mach 15 this law transfers to a higher range of temperature and artificial refrigeration is needed. The intersection point I of Fig. 1 divides, therefore, the general case illustrated: into two fields, natural temperatures on one side, refrigeration on the other side.

One deduces moreover the thermal possibility of other laws of descent to be inserted in the figure between the two limiting lines converging at point I. These laws would, for example, allow a reduction of the considerable range of 3600 kilometers connected with the optimum descent. A general analysis is, however, impossible. We have, therefore, proceeded by trial and error to the attainment of a type of descent of smaller range obtained by a larger degree of dive in the atmosphere and subject to three limitations: a maximum temperature of 1000 R; maximum physiological loading $\sigma/g \cong D/W \cong 3$; and arrival velocity at sea level of $M = 0.6$ as before. It has been possible to trace a descent of minimum range through what could be called graphical piloting. Starting tangent to the straight line of the constant temperature law, graphic piloting regulates the dive in the fashion shown in Fig. 2; and

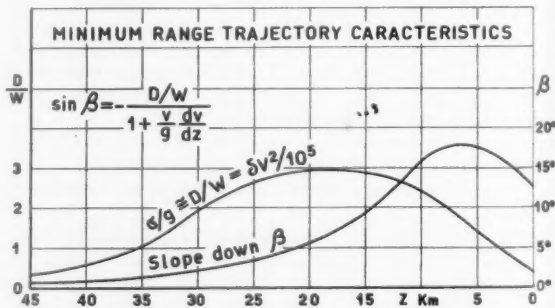


Fig. 2 Minimum range trajectory characteristics

gradually reaches at half altitude the maximum physiological loading $D/W = 2.98$ in order to reduce it successively in view of the speed limit prescribed for landing. The result of this attempt is very interesting, as one can see from Fig. 3, where the minimum range trajectory reduces 870 kilometers from

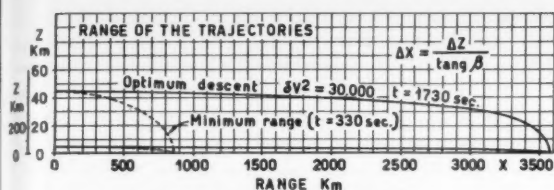


Fig. 3 Range of the trajectories

the range of 3600 kilometers obtained for the optimum descent.

In conclusion we find we have outlined the possibility of the descent of a tanker with acceptable dynamic and thermal conditions and with a ballistic range between a minimum and a maximum from the vertical of the starting point of the descent. Certainly the larger ranges may be used only in the case where they allow through a spiral descent the deflection of the trajectory toward a landing point closer to the vertical of the starting point. Otherwise, the minimum range descent appears more convenient.

In this case the return to the base airport must be performed, after the descent, with the help of suitable propulsive devices ready at the landing place. These propulsive devices should permit, with the economy of consumption of a subsonic flight, the transfer of the tanker via air back to the original base.

References

- 1 "Flying in the Stratosphere," by G. A. Crocco, *Aircraft Engineering*, August 1932.
- 2 "Gasdynamik," by A. Busemann, *Handbook der Exp. Physik*, vol. IV, part I.
- 3 "Su di in valore massimo del coefficiente di trasmissione del calore da una lamina piana a un fluido scorrente," by Luigi Crocco, *Rendiconti della R. Accademia, Nazionale di Lincei*, vol. XIV, December 1931 (NACA TM).
- 4 "Sulla trasmissione del calore da una lamina piana ad un fluido scorrente ad alta velocita," by Luigi Crocco, *L'Aerolenica*, February 1932.
- 5 "Supersonic Aerodynamic Heating with Continuous Fluid Injection," by E. B. Klunker and H. R. Ivey, NACA TR 990, 1950.

Unconditional Stability of Low-Frequency Oscillation in Liquid Rockets

(Continued from page 312)

By comparing the requirements of $-f_0$ and $-f_f$ it can be easily determined whether it is more effective to control the oxidizer or the fuel system. If the fuel and the oxidizer systems have the same values of P and D , it is always more ef-

fective to control the oxidizer system because $1/2 + K + H$ is always bigger than $1/2 - K - H$. Also, from Equation [17] we see that if $P_0 = P_f$ and $D = D_f$, a given increase of $n_*(0)$ can be obtained with a smaller decrease of P_0 than P_f .

Conclusion

So far, the discussions have been restricted to cases where all the time lags are sensitive, i.e., $\delta_i = 0$. From Equation [4] and [5] it can be shown (10) that, so far as unconditional stability n_{min} is concerned, the presence of an insensitive time lag δ_i has negligible effect for practical systems. Thus, a rational approach to the design for unconditional stability of low-frequency oscillation by adjusting the feeding system constants of a practical feed system is established. It requires an experimental determination of the transfer function $N = \mu_i/\varphi$ of the isolated feed system and some simple algebraic calculations. If the system requires the use of servo control for unconditional stability, a rational selection of the optimum transfer function of the feedback circuit is also provided. The problems of designing the feedback circuit and the mechanical servo are left to the designers.

References

- 1 "Aspects of Combustion Stability in Liquid Propellant Rocket Motors," by Luigi Crocco, *Journal of the American Rocket Society*, vol. 21, no. 6, November 1951.
- 2 "Low Frequency Combustion Instability in Liquid Rockets with Different Nozzles," by Sin-I Cheng, presented at Annual Meeting, AMERICAN ROCKET SOCIETY, December 1953.
- 3 "Servo-Stabilization of Combustion in Rocket Motors," by H. S. Tsien, *Journal of the American Rocket Society*, vol. 22, no. 5, September 1952.
- 4 "Stability of Flow in a Rocket Motor," by D. F. Gunder and D. R. Friant, *Journal of Applied Mechanics*, vol. 17, no. 3, 1950.
- 5 Discussion of the paper of Reference 4, by M. Yachter, *Journal of Applied Mechanics*, vol. 18, no. 1, 1951.
- 6 "A Theory of Unstable Combustion in Liquid Rocket Systems," by M. Summerfield, *Journal of the American Rocket Society*, vol. 21, no. 5, September 1951.
- 7 "Servo-Stabilization of Low Frequency Oscillations in a Liquid Bipropellant Rocket Motor," by F. Marble and D. W. Cox, Jr., *Journal of the American Rocket Society*, vol. 23, no. 2, March 1953.
- 8 "Stability and Control of Liquid Propellant Rocket Systems," by Y. C. Lee, M. R. Gore, and C. C. Ross, *Journal of the American Rocket Society*, vol. 23, no. 2, March 1953.
- 9 "Servo-Stabilization of Low Frequency Oscillations in Liquid Propellant Rocket Motors," by F. E. Marble, presented at Brooklyn Symposium on "Combustion Instability in Liquid Rocket Engines," October 1953. (This paper is unclassified but the Proceeding of the Symposium is confidential.)
- 10 "Theory of Combustion Instability in Liquid Rockets," by Luigi Crocco and Sin-I Cheng. Monograph, AGARD, NATO, chapter 2, section 7 to be published soon.

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Technical Notes

Problem of Cooling Nuclear Working Fluid Rockets Operating at Extreme Temperature¹

H. J. KAEPPLEL²

For an eventual application of nuclear power for rocket propulsion, the solution of the cooling problem for nuclear working fluid rockets is of primary importance. A method for cooling linear heat sources is suggested and studied. Possible local temperature reductions due to dissociation and ionization are investigated. A "complete" heat conduction coefficient is defined. Examples show that, even at operating temperatures beyond 10,000 K, sufficient cooling efficiency may be expected.

1 Introduction

THE thermodynamic properties of working fluids and the problem of cooling nuclear working fluid rockets operating at low pressures and temperatures up to 10,000 K were investigated by I. Sanger-Bredt (2, 3).³ Homogeneous temperature distribution throughout the heating chamber, with the exception of the boundary layer, was assumed. In the presented investigations, a cooling method characterized by a spiral motion of the working fluid toward the axis of rotation (heat source) of a cylindrical heating chamber is introduced, resulting in a radial and azimuthal temperature change.

This modification of Oberth's film cooling was adopted by the author as a basis for the presented investigations due to the following reasons. In trying to reduce extreme temperatures, certain thermodynamic properties of the working fluid, which might result in local temperature reductions due to strong increase in energy consumption in certain layers, will have to be exploited. These are mainly changes of state, dissociation, and ionization. When propagating through a thick layer of a fluid, thermal energy will first heat, then dissociate, and finally ionize part of the layer closest to the heat source. The energy left after penetration of this first part of the layer may already be reduced so far that only dissociation may occur in the next part, and after that the remainder of the thermal energy may merely heat up a third part of the layer to moderate temperatures. This picture is not changed if it is taken into consideration that these individually treated parts of the layer constitute a body heating up adjoining parts. If the heat flux is constant and continuous and an

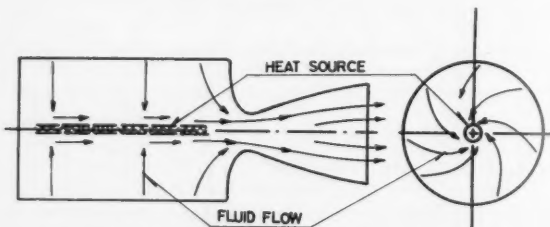


Fig. 1 Fluid motions inside the nuclear rocket motor

¹ Summary of paper presented at the 4th International Congress on Astronautics at Zurich, August 1953 (cf. Ref. 1).

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³ Numbers in parentheses refer to References on page 319.

EDITOR'S NOTE: This section of JET PROPULSION is open to short manuscripts describing new developments or offering comments on papers previously published. Such manuscripts are published without editorial review, usually within two months of the date of receipt. Requirements as to style are the same as for regular contributions (see first page of this issue).

appropriate continuous motion of the fluid against the heat source is maintained, the temperature at a certain fixed distance from the heat source may not change with time, i.e., the phenomenon occurs in its steady state, whereas the temperature decreases with increasing distance from the heat source, characterized by strong local temperature gradients. Confining this to a cylindrical heating chamber, the fluid will mainly have a radial motion toward the axis. Technically, the more easily accomplished and more stable spiral motion will be preferred (cf. Fig. 1). In the presented analysis, the working fluid is assumed not to participate in the heat generating process.

2 The Complete Heat Conduction Coefficient

In the derivation of a differential equation for the transport of thermal energy for the process described above, the working fluid is to be considered as a plasma due to the extreme operating temperatures. As the plasma is a mixture of neutral gas, electron gas, ion gas, a gas consisting of excited atoms, and a gas consisting of light quanta, the energy transport due to atoms and ions, due to free carrier electrons and radiation, is to be considered primarily. In this suggested cooling process, the working fluid will be heated from a very low temperature to extremely high temperatures maintained near the heat source. During the stationary process, the temperatures near the chamber walls should be well below the dissociation level. Therefore, in addition to the above considered modes of heat transport, the conduction of thermal energy due to dissociation and ionization has to be taken into consideration for this complete heat conduction coefficient. Hence

$$K = k_a + k_{dis} + k_{ion} + k_{el} + k_{rad} \dots \dots \dots [1]$$

where k_a is the conductivity of the atoms and ions; k_{dis} , k_{ion} , k_{el} , and k_{rad} are the energy transport constituents due to dissociation, ionization, free carrier electrons, and radiation. The expressions given in (1) for these constituents are:

for the conductivity of atoms and ions, and for carrier electrons

$$k_a = \frac{k^{3/2} \cdot T^{1/2} \cdot f}{4 \cdot 3 \pi^{1/2} M^{1/2} \cdot q} \dots \dots \dots [2]$$

$$k_{el} = \frac{\sqrt{2} k^{3/2} T^{1/2}}{\pi^{1/2} m^{1/2} q} \cdot \frac{n}{N - n} \dots \dots \dots [3]$$

for radiation

$$k_{rad} = \frac{4 \pi^2 k^4 T^3}{45 h^3 c^2 \rho \cdot \alpha} \quad \text{with} \quad \alpha = \frac{Z^2 h^6}{c \cdot m^{3/2} \cdot M^2} \cdot \frac{\rho}{(kT)^{3/2}} \dots \dots [4]$$

with

$$k_{dis} = e V_{dis} \cdot D_{ion} \frac{dn}{dT} \quad k_{ion} = e V_{ion} \cdot D_{ap} \frac{dn}{dT} \dots \dots [5]$$

and for the heat transport due to dissociation and ionization. Here k is the Boltzmann constant, T the temperature in $^\circ\text{K}$, f the number of the degrees of freedom, M the mean mass of the particles in the fluid (gr), q the mean cross section of the particles (cm^2), e the electronic charge, $e V_{dis}$ and $e V_{ion}$ the dissociation and ionization energies (electr-volts), D_{ion} the ionic diffusion coefficient, D_{ap} the ambipolar diffusion coefficient, l the free path length (cm), $h = h/2\pi$ is Planck's constant divided by 2π (erg. sec), c the velocity of light (cm/sec), ρ the density of the fluid (gr/cm³), α the mass absorption coefficient (German: Massenschwachungskoeffizient, cm^2/gr)

for a nondegenerate, nonrelativistic gas, Z the number of protons of the nuclei in interaction with radiation, and m the electronic mass. For further details, especially the bibliography on this subject, refer to (1). For substitution into the differential equation for the heat distribution, an approximation of this complete heat conduction coefficient by the analytical function

$$K = C \cdot T \cdot e^{\epsilon T^2} \dots \dots \dots [6]$$

was made. The coefficients for this function in the case of oxygen as a working fluid at a pressure of 1 atm were found to be

$$C = 0.15 \cdot 10^{-6} \left(\frac{\text{cal}}{^\circ\text{K cm sec}} \right) \quad \epsilon = 1.3 \cdot 10^{-7} (^\circ\text{K}^{-2}) \dots [7]$$

for the range $0 \leq T \leq 5000$ K,

$$C = 0.571 \cdot 10^{-7} \quad \epsilon = 6.0 \cdot 10^{-8} \quad 5000 \leq T \leq 12,000 \text{ K}$$

$$C = 0.571 \cdot 10^{-4} \quad \epsilon = 9.0 \cdot 10^{-11} \quad 12000 \leq T \leq 10^5 \text{ K}$$

The complete heat conduction coefficient for oxygen, together with the partial heat conduction coefficient due to free

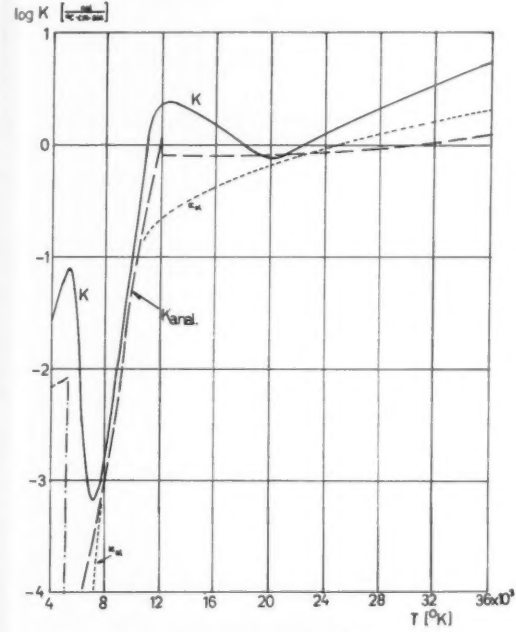


Fig. 2 Heat conduction coefficients for oxygen

electrons and the analytical approximation are presented in Fig. 2. The inverse temperature conductivity

$$\Delta = \frac{C_p \cdot \rho}{K} \dots \dots \dots [8]$$

presented in Fig. 3 for the case of oxygen at a pressure of 1 atm, also appears in the solution of the temperature distribution equation. This factor is kept constant for certain ranges, as also shown by the dotted line in Fig. 3.

3 An Approximate Expression for the Velocity of the Working Fluid Flow

If the differential equation for the heat distribution in the working fluid with spiral motion is to be solved analytically, a very simple expression for the velocity distribution, namely, a function of r^{-1} (r being the radius in cm), is required. The investigations, presented in detail in (1), lead to the simple expression

$$v = \frac{r_a}{r} v_0 = \frac{R_{aK} \cdot v_0}{R} \quad R_{aK} \cdot v_0 = \text{const} \dots \dots \dots [9]$$

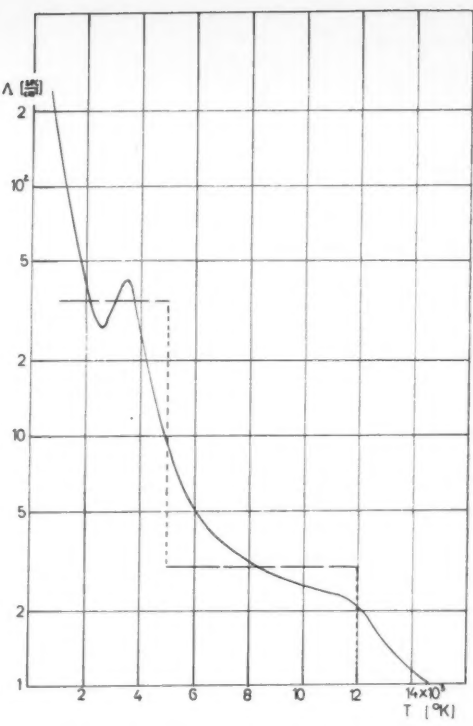


Fig. 3 Reciprocal of thermal diffusivity

The relation between the radius and the angle of azimuth is given by

$$R = R_{aK} \cdot e^{-a(\theta - \theta_0)} \dots \dots \dots [10]$$

where

$$a = \left[\frac{4 \pi \cdot z \cdot v_0 \cdot V}{\dot{V}^2} - 1 \right]^{-1/2} \dots \dots \dots [11]$$

is an abbreviation. In the above equations, $R = r/r_K$ is the reduced radius, r the radius (cm), r_a the peripheral radius (chamber walls), r_K the radius of the heat source, $R_{aK} = r_a/r_K$, θ the angle of azimuth, θ_0 the initial angle of azimuth, v the fluid velocity, v_0 the initial velocity at $r = r_a$ and $\theta = \theta_0$, v_r the radial velocity component, v_θ the azimuthal velocity component, V the chamber volume (cm³), and \dot{V} the volumetric fluid flow (cm³/sec). The relations between the two velocity components are

$$v_r = -a \cdot v_\theta \dots \dots \dots [12]$$

where a is the abbreviation given by Equation [11].

4 Determination of the Radial Temperature Distribution

Together with the analytical expressions for the complete heat conduction coefficient and the velocity distribution, the differential equation for the heat transport in this process

$$\frac{\partial}{\partial t} (\rho \cdot X) = \text{div}(K \text{ grad } T) + W - \text{div}(\rho \vec{v} \cdot X);$$

$$X = \int^T C_p dT \dots \dots [13]$$

can be solved analytically. Here, ρ is the density of the fluid, T the temperature, X the enthalpy, K the complete heat conduction coefficient, and \vec{v} the fluid velocity. With the hydrodynamic equation of continuity

$$\text{div}(\rho \vec{v}) + \frac{\partial \rho}{\partial t} = 0$$

and Equations [6], [8], [9], and [12], the differential equation can be reduced to

$$-2 \epsilon T e^{T_0} \frac{dT}{dR^2} - 2 \epsilon T e^{T_0} \frac{1}{R} \frac{dT}{dR} [1 + 2 \nu] - \left\{ 2 \epsilon e^{T_0} + (2 \epsilon T)^2 e^{T_0} \right\} \left(\frac{dT}{dR} \right)^2 = \frac{2 \epsilon \cdot r_K^2}{C(1 + a^2)} \cdot W$$

with

$$\nu = \frac{c}{2} \Lambda - \frac{c^2}{8 r_{a2} v_0^2} [1 + c \cdot \Lambda] \quad \Lambda = \frac{C_p \cdot \rho}{K} \quad c = \frac{\dot{V}}{\pi \cdot z} \dots [14]$$

being an abbreviation. W is the energy per unit volume and time (erg/cm³sec), the other notation as explained above. In a plasma, W can be represented by the expression

$$W = \frac{\sigma}{e^2} F^2 \dots [15]$$

where σ is the electric conductivity, e the electronic charge, F the constant field constituent. Using the Franz-Wiedemann law and the analytical expression for the heat conduction coefficient, Equation [6], F becomes

$$F^2 = \frac{2k^2 E}{\pi \cdot r_K^2 \cdot z \cdot C} e^{-\epsilon T_0^2} \dots [16]$$

where E is the energy production per unit time (erg/sec) of the heat source. With the abbreviation

$$\lambda = \sqrt{\frac{2}{\pi \cdot z}} e^{-\frac{\epsilon}{2} T_0^2} \left[E \frac{1}{1 + a^2 C} \right]^{1/2} \dots [17]$$

and the new independent variable $U = e^{\epsilon T^2}$, the differential equation becomes

$$\frac{d^2 U}{dR^2} (1 + 2 \nu) + \frac{1}{R} \frac{dU}{dR} + \lambda^2 U = 0$$

with the solution

$$U = e^{\epsilon T^2} = R^{-\nu} Z - \nu(\lambda R)$$

resulting for the radial temperature distribution

$$T = \left[\frac{1}{\epsilon} \left\{ \ln [J_\nu(\lambda R)] + \ln A - \nu \cdot \ln R \right\} \right]^{1/2} \dots [18]$$

In Equation [18], $J_\nu(\lambda R)$ is the Bessel function, and A the constant of integration. For the determination of this constant, not the general solution of the differential equation but a particular solution is considered. T_0 is the maximum temperature of the fluid obtainable after an enthalpy X_0 is imparted on the system. With $X_0 = E/\dot{G}$ (\dot{G} = mass flow rate, gr/sec), the pertinent temperature T_0 is obtained from an enthalpy (Mollier) diagram. The constant A is then determined from

$$e^{\epsilon T_0^2} = A \cdot J_\nu(\lambda) \dots [19]$$

Thus, all relations necessary for determining the radial temperature distribution are given.

5 Three Examples for the Temperature Distribution

Three examples are presented for a nuclear working fluid rocket with oxygen as a working fluid, operating at a chamber pressure of 1 atm. This pressure is arbitrarily selected without consideration of possible technical realization.

Example 1: Required exhaust velocity 17,000 m/sec, weight flow of working fluid 20 kg/sec, resulting thrust 35,000 kg. Peripheral radius of chamber $r_a = 50$ cm, length of chamber $z = 200$ cm, radius of heat source (arbitrary selec-

tion) $r_K = 1$ cm, injection velocity of working fluid $v_0 = 10$ cm/sec. Energy production of heat source $E = 7 \times 10^9$ cal/sec, maximum fluid temperature T_0 (at $r = r_K$) = 2·10⁴ K.

Example 2: Required exhaust velocity as for example 1, chamber data from example 1; weight flow of working fluid 40 kg/sec. Energy production of heat source $E = 27 \cdot 10^9$ cal/sec, maximum fluid temperature $T_0 = 100,000$ K. All other data as in the first example.

Example 3: Required thrust 400,000 kg. Weight flow of working fluid 120 kg/sec. Energy production of heat source 1.5×10^{10} cal/sec, maximum fluid temperature $T_0 = 250,000$ K. All other data as in the first example.

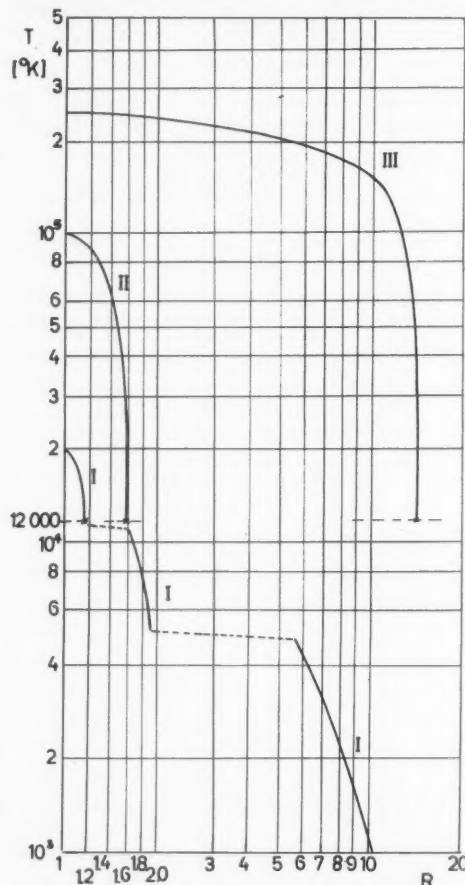


Fig. 4 Radial temperature distribution in sweat-cooled rocket chamber (three examples)

The radial temperature distributions for these examples are presented in Fig. 4. For the latter two examples, only the temperature distributions above 12,000 K are given, as this range is of the most interest.

6 Discussion of Results

The presented analysis points a way how the temperature of working fluids heated by nuclear energy may be reduced below 10⁴ K near the chamber walls. It is shown that clearly an ionization and a dissociation layer are formed in the working fluid. The temperature drops considerably directly behind these layers. This can be explained by the high energy consumption required for ionization and dissociation. Furthermore, with this decrease in temperature behind the ionization and dissociation fronts, a strong decrease of the complete heat conduction coefficient is noted which further increases the temperature drop.

The third example already constitutes a strong extrapolation

tion from the presented data. In this higher temperature range, multiple ionization has to be taken into consideration. Also, the mean mass absorption coefficient as given in this analysis is no longer valid. Band and line absorption of thermal radiation has to be considered, especially photoionization and possibly also photo-dissociation at extreme temperatures. It is very likely that working fluids may be employed consisting of a number of specifically selected gases, with their various ionization levels distributed over the range of maximum radiation intensity.

References

- 1 "Die Verwendung exothermer Kernreaktionen als Energiequelle für Raketenantriebe," by H. J. Kaeppler. Paper presented at the 4th International Astronautical Congress at Zurich, August 1953 (in print).
- 2 "Zur Thermodynamik der Arbeitsgase von Atomraketen," by I. Sänger-Bredt. Paper presented at the 4th International Astronautical Congress at Zurich, August 1953 (in print).
- 3 "Wasserstoff bei hohen Temperaturen," by I. Sänger-Bredt, *Z. Naturforsch.* vol. 6a, pp. 103-112, 1951.

Flow Separation in Overexpanded Supersonic Exhaust Nozzles¹

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THIS paper is concerned with the flow characteristics of a compressible fluid in the diverging portion of a supersonic de Laval nozzle when the back pressure of the surrounding medium exceeds that which corresponds to isentropic expansion at the exit. The question is one that arises in a jet propulsion device operating at a lower altitude than that for which its exhaust nozzle is designed; it may also arise in steam turbines running with throttled flow, and in supersonic wind tunnels under certain conditions.

Although this problem has been discussed in the literature by Buchner (1904), Flugel (1917), Stanton (1926), Stodola (1927), Fraser (1940), and others, the flow processes under certain conditions are not yet understood. It is known that, as the back pressure is gradually lowered, while the reservoir pressure is kept constant, the flow in a de Laval nozzle undergoes a transition from a subsonic isentropic process to a supersonic process with a normal shock after the throat followed by a subsonic regime. As the back pressure is reduced still further, the normal shock moves downstream until, at some limiting value of the back pressure p_1 , the normal shock is supposed to stand at the exit of the nozzle. When the back pressure is set still lower, at some value between p_1 and the isentropic exit pressure p_0 , it is usually assumed that the issuing jet adjusts itself to the higher pressure by means of an oblique shock wave located at the exit ring of the nozzle. This condition has been studied by Prandtl (1907) and by Meyer (1908).

It has been found, in the present investigation, that the

latter flow configuration holds only when the back pressure exceeds p_0 by less than a certain amount, i.e., up to a back pressure p_2 , and that p_2 is definitely less than p_1 . For a back pressure too low for a normal shock (less than p_1) and too high for the oblique shock type of flow (more than p_2), the jet detaches symmetrically from the diverging conical wall of the nozzle. The point of separation moves upstream from the mouth of the nozzle, in a definite manner, as the back pressure is raised above p_2 . Furthermore, it appears that the regime of detached flow persists even when the back pressure exceeds p_1 , so that the predicted normal shock at the exit of the nozzle does not occur (Fig. 1).

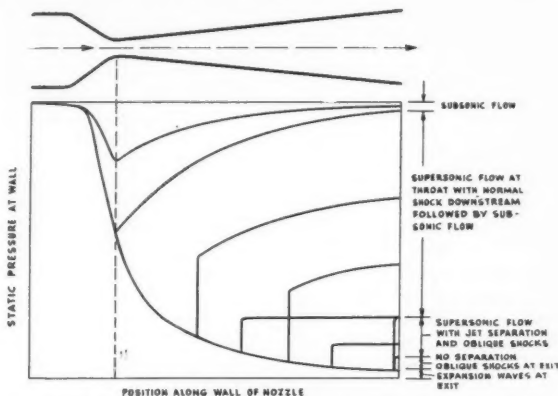


Fig. 1 Pressure distribution in a Laval nozzle corresponding to different possible regimes

The nozzle experiments were conducted with a 750-lb thrust rocket motor burning nitric acid and aniline as propellants. Although the flow process in the nozzle was described, above, in terms of controlled variations of the back pressure, the experiments were actually conducted with one back pressure, namely, atmospheric pressure (14.1 psia), and it was the chamber pressure that was varied in a systematic manner. The conical wall of the exhaust nozzle was fitted with a number of static pressure taps connected to a bank of mercury manometer. Each run lasted about 30 seconds, which was ample time for equilibrium conditions to be established.

The chamber pressure was varied over the range from about 200 psia to 350 psia, corresponding to pressure ratios of 14 and 25, respectively. The throat diameter of all nozzles tested was 1.545 in. Five nozzles have been used for the tests made to date: (1) Half-angle of conical divergent section = 15°; area ratio = 3.5. (2) 10°; 10.0. (3) 15°; 10.0. (4) 20°; 10.0. (5) 15°; 20.8.

The mixture ratio of the propellants was maintained at 1.9 lb nitric acid/lb aniline in most of the runs, corresponding to a theoretical gas temperature of 3650 F. A few runs were made at a mixture ratio of 3.0, corresponding to a temperature of 5050° F. Thus, the variables under control in these experiments, each of which was independently varied, were (a) pressure ratio, (b) nozzle area ratio, (c) nozzle divergence angle, (d) gas temperature.

In each test, a record was taken of the pressure variation along the wall of the nozzle. A typical curve of static pressure versus area ratio follows the theoretical isentropic expansion curve down to the point of separation below atmospheric pressure, and then abruptly jumps up to approximately atmospheric pressure (Fig. 2). The point of departure from the isentropic curve is interpreted as the point of flow separation. The precision of the curves was such that the point of separation could be defined to within ± 0.10 area ratio units. That the jet detached itself symmetrically was established by taking pressure readings with other taps circumferentially spaced around the nozzle wall. The shape of the pressure curve upstream of the separation point fitted a theoretical isentropic curve closely enough to permit the determination of the effect-

¹ This paper was presented originally at the Institute of Fluid Mechanics and Heat Transfer in Los Angeles on June 22, 1948, but the proceedings were never published. Interest in this subject is quite active at present, and because of the many requests that have been received for this paper, the editors decided to make it broadly available by publishing it at this time.

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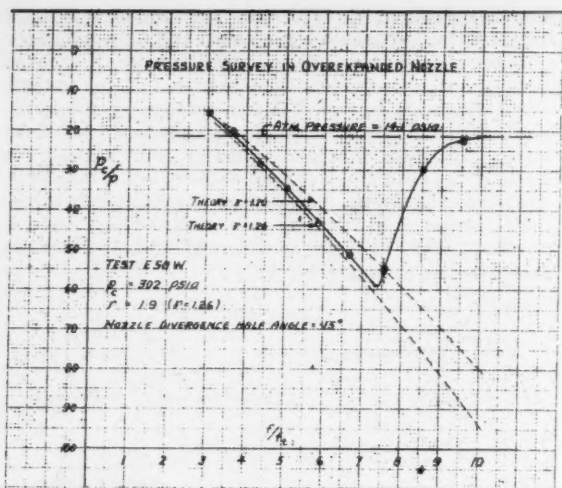


Fig. 2 Pressure survey in overexpanded nozzle (typical test)

ive adiabatic exponent γ . In addition, a record of the thrust delivered by the rocket motor was taken in each test, and agreement within about 1% was found with the integrated pressure thrust on the nozzle wall.

The results have been summarized in a significant form by plotting the area ratio at which separation occurred against the ratio of chamber pressure to atmospheric pressure, for each nozzle. The curve for the 15-deg nozzle shows at one end that, with a pressure ratio of 15, detachment takes place at an area ratio of 5.7, and at the other end of the curve a pressure ratio of 25 produces detachment at an area ratio of 8.3. The curve remains relatively unchanged by changes in gas temperature or length of nozzle. The curve seems to be shifted parallel to itself by changes in the nozzle cone angle (Fig. 3).

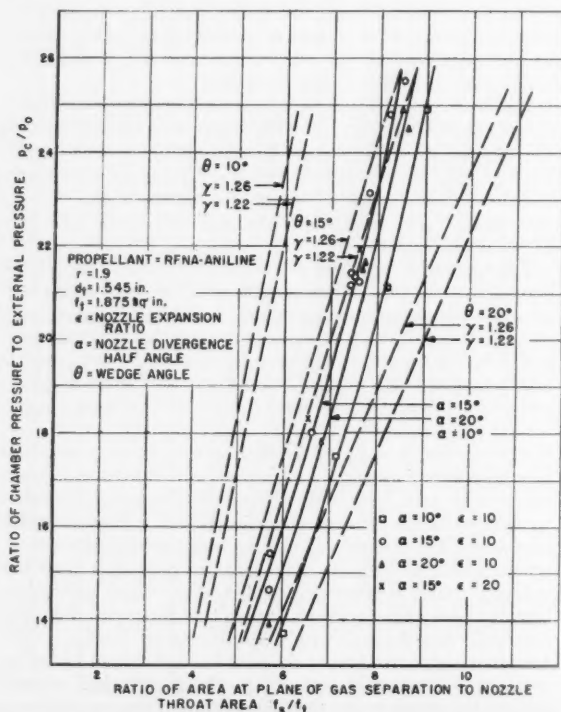


Fig. 3 Variation of plane of gas separation with chamber pressure

This systematic behavior has not been described in the literature, although the phenomenon of detachment has been observed before. An attempt is made to establish a hypothesis for predicting the nature of these pressure ratio-area ratio curves. It is assumed that the detachment of the jet is accompanied by an oblique shock wave near the nozzle wall, and that the angle and strength of the oblique shock correspond to the "wedge angle" by which the stream lines adjacent to the wall are deflected (Fig. 4). It is reasonable to ex-

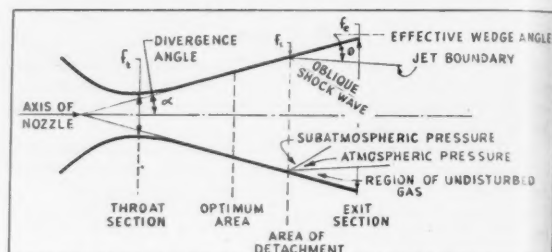


Fig. 4 Hypothetical flow structure in overexpanded exhaust nozzle

pect that the wedge angle is small and of the same order as the half angle of divergence of the nozzle. By means of one-dimensional supersonic nozzle theory and one-dimensional oblique shock theory (applicable to the local region near the wall), a system of equations is evolved that can be solved for the area ratio of separation as a function of pressure ratio, for various parametric values of the wedge angle. It is found that the experimental curve for each nozzle runs reasonably parallel to the family of theoretical curves for constant wedge angle, and that the hypothetical wedge angle for each nozzle shape may then be determined to within about 1 deg. (Cf. Fig. 3.) The interesting conclusion is that, over the range of conditions tested, the wedge angle is almost independent of the nozzle divergence angle, and that it is relatively unaffected by changes in pressure ratio, gas temperature, adiabatic expansion exponent, and nozzle length.

The preceding generalization has turned out to be a useful one and provides some insight into the nature of the flow process in overexpanded supersonic nozzles.

Bibliography

- 1 "Steam and Gas Turbines, Vol. I," by A. Stodola (English translation by Loewenstein), McGraw-Hill Book Co., Inc., New York, N. Y., 1927, Sections 32, 33, 36, 42a.
- 2 "On the Flow of Gases at High Speeds," by T. E. Stanton, *Proceedings of the Royal Society, London*, vol. 111A, 1926, p. 306.
- 3 "Flow Through Nozzles at Supersonic Speeds," by R. P. Fraser, Rep. WA-1513-1a, Ministry of Supply, DSR, EMR, London, 1941.
- 4 Articles by Buchner, Prandtl, Meyer, Flugel, mentioned in the text, are reported in Ref. 1.

APPENDIX A

An Investigation of Flow Separation with a Transparent Nozzle

A concurrent investigation, also hitherto unreported in the standard literature, concerning the flow pattern in an over-expanded nozzle, was undertaken in 1949 by J. D. McKenney as an Ae.E. thesis at the Jet Propulsion Laboratory under the supervision of the senior author. For comparison with the preceding report, some of the pertinent observations are quoted here. Full details are available in McKenney's thesis.

The flow tests were made with a small two-dimensional nozzle formed by parallel glass sides separated by brass converging-diverging nozzle blocks. The space between the glass plates was 0.37 in.; the throat section was 0.20 in. high; the exit section was 1.60 in. high; the half angle of the diverging portion was

15 deg; the exit-to-throat area ratio was 8.0. Static pressure orifices were drilled along the wall of each nozzle block, and a spark shadowgraph system was used to determine the flow pattern. Dry nitrogen was fed to the nozzle at stagnation pressures ranging from 174 psia to 294 psia; the back pressure for all the tests was 13.1 psia.

Fig. 5 is a typical shadowgraph which shows the following features: the separation pattern is precisely symmetrical; the flow does detach from the wall quite clearly except for the ex-

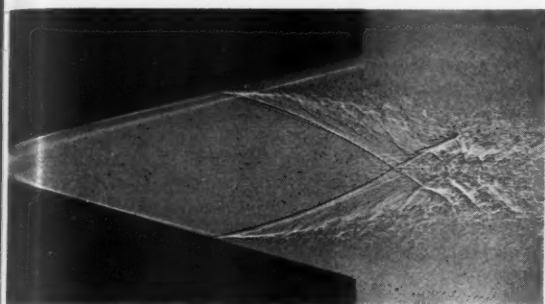


Fig. 5 Spark shadowgraph of flow in overexpanded Laval nozzle (pressure ratio 19.4)

pected turbulent mixing boundary; oblique shock waves accompany the detachment of the flow. The pressure distributions along the nozzle wall followed the isentropic expansion curves all the way to the plane of separation, and then jumped sharply up to approximately the level of the back pressure, as in the rocket tests reported above. The area ratio of separation is correlated with the chamber-to-exit pressure ratio in Fig. 6 in a manner to facilitate direct comparison with the rocket motor results in Fig. 3. It can be seen that the wedge angle (stream deflection) at the point of detachment

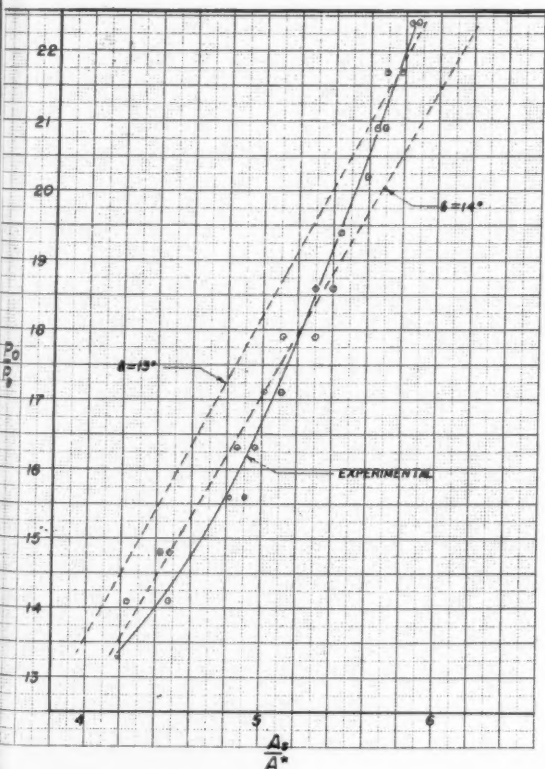


Fig. 6 Experimental separation area ratio compared with area ratio computed for two different deflection angles

is about the same for the two-dimensional nozzle as for the axisymmetric one, that is, about 14 and 16 deg, respectively.

Another way the data can be correlated is by means of the simple observation that the ratio of separation pressure to back pressure was approximately constant for all the tests, between 0.38 and 0.41. In the rocket tests, this ratio tended to decline from about 0.40 at low chamber pressure (170 psia) to about 0.34 at a pressure of 360 psia.

A rather interesting finding was that the separation pattern



Fig. 7 Unstable asymmetric flow pattern at pressure ratio of 8.7

was always steady and symmetrical at pressure ratios above 12, but below this pressure the flow tended to cling to one wall or the other of the nozzle in unstable fashion (Fig. 7). Similar unsteadiness has been observed in rockets nozzles at low chamber pressures.

The Vulnerability of Satellite Vehicles to Countermeasures¹

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Introduction

Serious proposals have been made recently for the expenditure of some four billion dollars of public money to develop and establish a space station or satellite vehicle. This artificial moon would revolve around the earth in a plane through its axis once in two hours at a height of about a thousand miles above the earth's surface (1).³ It is claimed that this station would be of great military value, both as an observation post and as a launching platform for guided missiles. It is further claimed that it could maintain itself against attack by guided missiles from the earth's surface (2). The author of this report does not admit this last claim; on the contrary, it seems to him that the expenditure of a small fraction of the cost of such a station on countermeasures could prevent the establishment of the station or could destroy it after its establishment.

Method of Attack

A direct hit on the satellite by a two or three-stage rocket launched from the earth's surface would be very difficult. The target area would be some 10,000 sq ft at a range of 15,000 miles, and incredible accuracy would be required. Elaborate guiding or homing devices are, however, not necessary. The satellite is very vulnerable to small particles traveling with orbital velocity, and a reasonable rocket could carry a warhead of fine shot with a very small bursting charge.

¹ Summary of a talk given before the New York Section of the AMERICAN ROCKET SOCIETY, April 23, 1954.

² Professor of Physics, Columbia University, and Senior Staff Member, Watson Lab.

³ Numbers in parentheses refer to References at end of paper.

This rocket should be aimed to settle in the counter orbit to that of the satellite and should be timed to burst about one half of a circumference away from it. The cloud of shot produced would not disperse indefinitely but would all come back near to the point of burst every two hours, though the variation in speed would gradually spread the shot around the whole orbit. Adjusting the bursting charge to give a maximum dispersion about equal to the probable error of aim, one mil say, at a range of 15,000 miles, the shot are spread over about 20 billion sq ft, and about one shot in a million should hit the satellite as it passes through the cloud. However, the satellite must pass through the cloud or shot again and again, at first at intervals of one hour, and later continuously, and suffer hits by one shot in a million each hour.

An Estimate of the Cost of Attack

A pellet in the counter orbit would have a velocity of attack of twice the orbital velocity, about 46,000 fps, and would have 38 ft lb of energy, sufficient to knock out a man, if it weighed one millionth of a pound. A pellet of this weight would have a diameter of about fifteen mils and at such speeds could penetrate about one tenth of an inch of steel, while if the whole weight of the satellite, four or five hundred tons, went into a steel skin, this would only be about two tenths of an inch thick.

If only one per cent of the weight of a satellite vehicle were put into the counter orbit in the form of fine shot as described, we would expect some seven thousand hits per hour, and it should be possible to do this for less than a million dollars. The author feels that there is ample margin in these estimates to reach his conclusion that a space station could not easily be maintained against hostile action of this kind.

References

- 1 "Man Will Conquer Space Soon," A Symposium, *Collier's Magazine*, March 22, 1952.
- 2 "Across the Space Frontier," Edited by C. Ryan, Viking Press, New York, 1952, particularly pp. 55-56.

A Recoverable Propulsion System for Long-Range Rockets

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WHEN the staggering cost of large military and experimental rockets was realized during World War II, many proposals were made to reduce the cost, but most of these proved unsatisfactory.

This article is a proposal for salvaging the propulsion unit, which normally consists of a rocket motor, with its component fuel pump and the rocket jacket itself. Salvaging the propulsion unit is important when one considers that about ninety per cent, or \$510,000, of the German V-2 rockets of World War II were salvageable.

In the rocket shown in Fig. 1 the propulsion unit "A" and the payload "B" are separate units. Payload, in rocket terminology, depends on the use to which the rocket is put. For example, payload "B" may be an atomic explosive for the

military, or an intercontinental load of mail for the postal services, or weather-recording devices for the meteorological services, etc. The propulsion unit's forward thrust holds it in contact with the payload until the unit's fuel is exhausted. Following this, the unit is separated from the payload by a small solid propellant rocket "C" which pushes against the unit's forward momentum, until the unit's speed is reduced to zero. Then a parachute opens and floats the unit down to earth so that it can be used again.

The recovery of the propulsion unit is logically the next major problem. Thus, in Kenneth W. Gatland's book, "Development of the Guided Missile," the author proposes several ways for recovering empty steps. Some of these ideas can be applied to this article.

The first idea was worked out for the German A-9/A-10, a two-stage rocket, which was designed to bombard the United States. It was to incorporate air brakes and parachutes which had double panels with compressed air between in its canopy. These would form a parachute which would not be dependent on air density.

The second idea was to use "ribbon" parachutes, with some thrust braking, or to have them fitted with wings that would convert the empty steps, or propulsion unit, into a form of glider.

In conclusion, since the tremendous cost of rocket experiments on a large scale has hampered their development, the savings proposed in this article should, I feel, be experimented with further.

Utilization of Radio Frequencies in Connection With Rockets

GEORGE E. STERLING¹

Federal Communications Commission, Washington, D. C.

The use of radio frequencies both for communications and for transmitting and receiving information from rockets raises technical and regulatory problems. In addition to national, it may involve international considerations.

THERE are several interesting radio frequency problems that arise in connection with navigation and communication with rockets. Important factors are the following: First, the frequency should be high enough so that it is not reflected or attenuated by the ionosphere. This means that the operating frequency should be above perhaps 50 mc. On the other hand, communication over the tremendous distances involved will require high powers and high antenna gains on the ground. The major factor is that the size of the antenna system on the rocket will be severely limited by streamlining and space considerations. These factors indicate that a frequency of perhaps as high as in the order of thousands of megacycles might be used. On the other hand, if we get too high on frequency, above 24,000 megacycles and higher, the earth's atmosphere will attenuate the signals. There is a limit to the available gain from antennas which will be imposed by the size of the structure involved together with the necessity for tracking and the required tolerances for the shape of the parabolic antenna system.

One foreseeable difficulty is that frequencies of this order are regarded in many international agreements as being purely local in scope, with the result that there may be some problems in obtaining sufficiently clear frequencies on a world-wide basis.

The regulation of communications on a world-wide basis is handled by the International Telecommunications Union

Presented at April 2, 1954; meeting of the National Capital Section of the AMERICAN ROCKET SOCIETY, Washington, D. C.

¹ Commissioner, Federal Communications Commission.

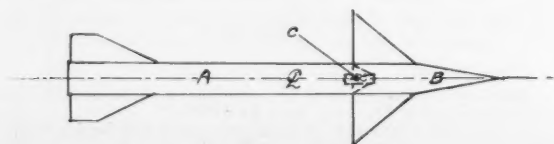


FIG. 1 PROPOSED ROCKET

Received March 10, 1954.

¹ Student, age 12.

which is a special body coming under the United Nations. If the details of the operation involve interference to radio services in other countries, it will perhaps be necessary to make provision for this use at succeeding international conferences. None of the present allocations in my opinion could be stretched to include this type of operation. Perhaps when our technological development has reached the point of building and flying rockets or other vehicles which are not tied to the earth, we will have progressed sociologically to the point where we may have developed a means of obtaining international agreement on problems of this kind.

The high power transmission to a rocket will require tremendous effective radiated powers, while there may be some discrimination from the antenna against signals along the ground. There may be considerable local transmission of the signals arising out of scattering and turbulence in the troposphere as well as the ionosphere.

Recently an interesting article appeared in the *General Electric Review* on the problems associated with guided rocket operations, in which the following statement was made: "The ionized exhaust stream absorbs, reflects and diffuses radio waves. This makes it difficult to send information from the missile and to send guidance signals to it. At high altitudes it is particularly troublesome because the exhaust seems to grow 'bushy' or 'blossom out' as the atmospheric pressure decreases."

Another consideration in communications of this type might be the Doppler effect. If we assume a satellite 200 miles above the earth, the required velocity for it to retain its orbit would be approximately 18,000 mph. At this speed one would have a Doppler frequency shift of approximately 27 cycles per megacycle. Thus, if a frequency of 1000 megacycles is used for communications, the received frequency would be 27 kilocycles high when the satellite is approaching the receiving point and 27 kilocycles low when receding, or a total frequency change of 54 kilocycles. In the case of a rocket attempting to leave the gravitational influence of the earth, considerably greater velocities will be involved with a proportionately greater Doppler shift. At the escape velocity of 25,000 mph the Doppler shift would be about 40 cycles per megacycle. When one considers that communication with the rocket at considerable distances would be desirable, narrow bandwidths will be required and thus the Doppler shift may be a considerable problem. It should be kept in mind that the relative speed between the rocket and the earth end of the circuit is the governing factor, and thus the Doppler shift would be variable depending on whether the earth point was rotating toward or away from the rocket.

I believe that serious consideration is being given to artificial satellites which will circle the earth many times in one day at distances varying from 200 to 1000 miles from the earth's surface. By means of an East and West Coast transmitter in the United States sending information by bursts when the satellite was passing overhead, communication with such a vehicle might be possible.

With respect to the function of "tracking" it would seem that radar techniques are called for. In this event, it is pointed out that the Federal Communications Commission has provided for "radiopositioning" in various radionavigation bands where such functions have been determined to be in the public interest. Usually such functions have been performed by agencies whose operations fall in regular categories of Commission services such as public safety, marine, aviation, and industrial. Part 5 of the Federal Communications Commission's Rules has been utilized as the governing regulations involving miscellaneous scientific experimental projects wherein frequency usage and service problems have not required the promulgation of special service rules.

I believe that the principal regulatory problems in connection with communications with rockets appreciably beyond the earth will be in providing interference-free channels which now are regarded as purely local in character. It is quite ob-

vious that we have to have some understanding about the possibility of "jamming." We have to have assurances from other nations in the world that jamming would not be undertaken or that special provisions be made to operate in the presence of jamming. This problem would be particularly acute in the case of a satellite which might be used for observation or other purposes.

In conclusion, I believe that there will be many technical problems as well as regulatory problems associated with communications in connection with rockets that travel far from the earth. I am not aware of any study which has been made in this regard, but I think it would be a very fruitful field for exploration.

CORRECTION: In the July-August issue of *JET PROPULSION* the following typographical errors were made in Leon Green, Jr.'s paper, "Unstable Burning of Solid Propellants," page 252:

First column, line 10. The sentence should read: "Cheng's analysis is predicated upon a mechanism for self-excitation of the oscillations which assumes that the instantaneous burning rate of the propellant (at a given initial propellant temperature) depends on pressure alone," etc.

Second column, line 7 from bottom of first paragraph. The sentence should read: "A reasonable conjecture is that the helical inhibiting pattern provided the needed dissipative action by inducing a helical flow around the grain," etc.

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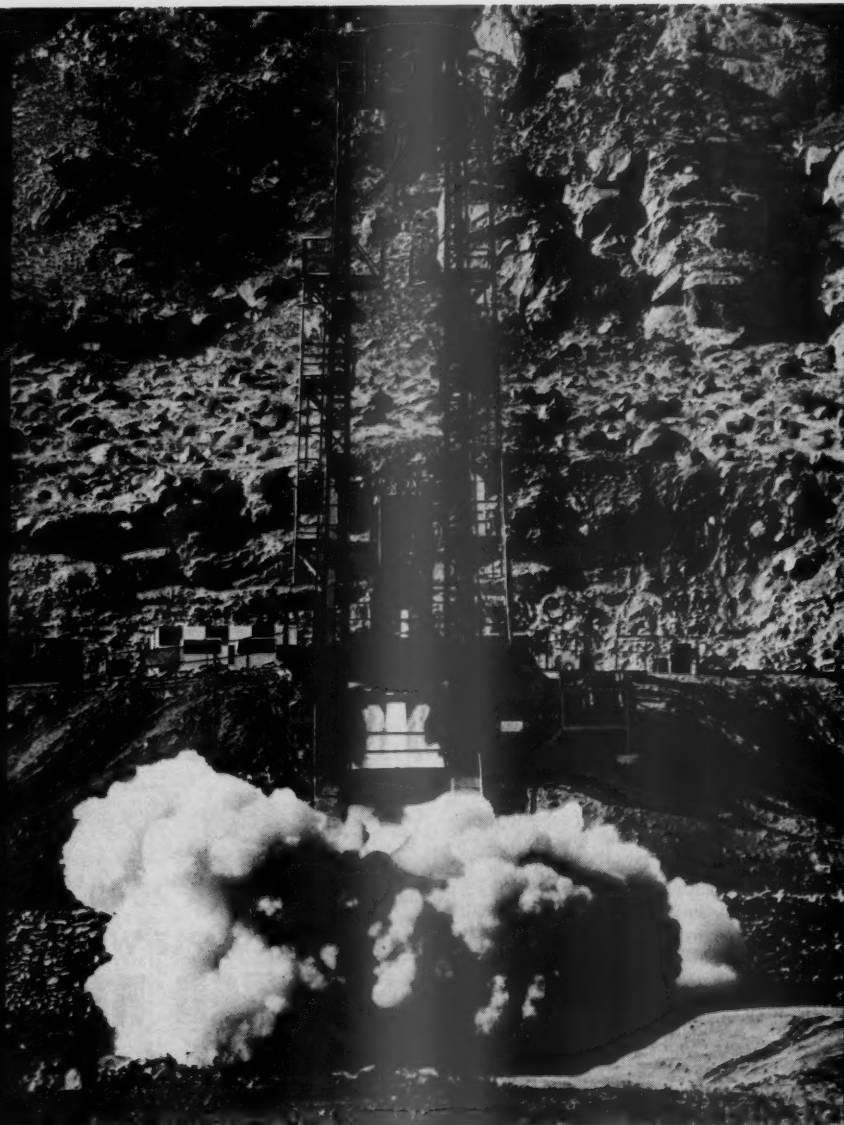
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U. S. Army photo

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Jet Propulsion News

Alfred J. Zaehring, American Rocket Company, Associate Editor

Rocket Progress

Missiles. Of the large number of postwar American missiles, only a few have survived to the production stage. Nike is the only rocket missile that is available in large numbers. Nike batteries are now springing up around New York, Philadelphia, Baltimore-Washington, Boston, Norfolk, Cleveland, Detroit, Chicago, Denver, Hanford, Seattle, and Los Angeles. Army Ordnance is activating the Charlotte, N. C., Ordnance Missile Plant to take over production in 1955 of the missile now produced by Western Electric and Douglas Aircraft. Present markings and characteristics of Nike's on public view indicate that a solid propellant booster supplied by Goodyear Aircraft is being used.

Another rocket missile to go into production is the Navy air-to-air Sparrow I. After flight testing over 100 prototypes,



U. S. Army

Honest John on launcher

the Sperry Farragut Corp. at Bristol, Tenn., is to be responsible for turning out the highly maneuverable missile which is light and compact enough to be carried in multiple units and launched from fighter-type aircraft. Other new missiles now in production and being delivered to field artillery units are the Honest John (a free-flight rocket of 18-mile range) and the Corporal (a guided rocket with range "over 50 miles"), both developed by Army Ordnance. Meanwhile, the Chrysler "Redstone" ground-to-ground, long-range missile is now undergoing a flight test and evaluation program.

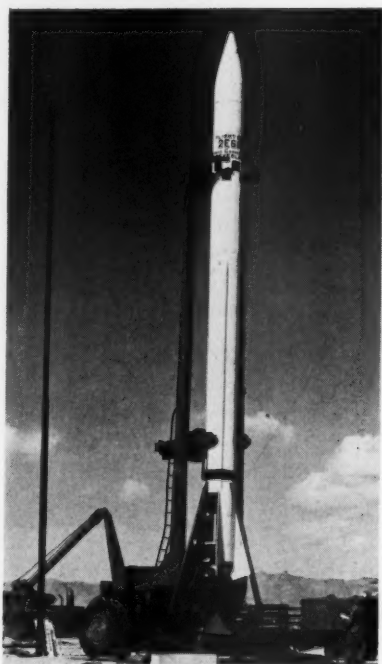
Boeing's F-99 Bomarc missile is not yet in production, while no production statement has been released on the Hughes F-98 Falcon air-to-air missile. Three other missiles, all subsonic and turbojet-powered, are in various stages of development and production. The Navy Chance-Vought Regulus still sports its retractable landing gear and indicates that it is still in the flight test stage. Little has been said about the Northrop Snark. However, the Air Force has placed tactical groups of the Martin Matador in operation in Germany along the Iron Curtain.

RATO. The services have lived with the familiar 14AS-1000 with its smoky exhaust, composite asphalt-perchlorate solid propellant for many years. These units were developed during the war and have been the workhorses of the services. More recently the 14DS-1000 with its double-



U. S. Navy

F3D carries nest of Sparrows



U. S. Army

Corporal being elevated on its transporter-erector



Aerojet-General

High-thrust RATO

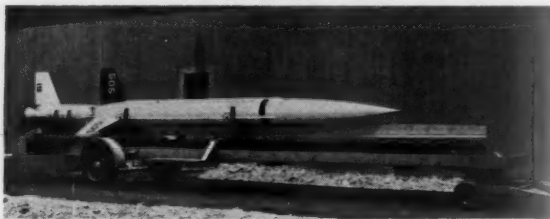
EDITOR'S NOTE: The information reported in this Section has been selected from approved news releases originating with the Department of Defense, private manufacturers, universities, etc., and from published news accounts in journals and newspapers. The reports are considered generally reliable, although no attempt has been made to verify them in detail.

base propellant has seen important applications. The newest production RATO is Aerojet's 15KS-1000, but is so new that such aircraft as the B-47 are still plainly marked "Use Only 14AS-1000 or 14DS-1000 Rockets."

Industrial firms such as Grand Central Aircraft, Phillips Petroleum, Standard Oil of Indiana, and Thiokol Chemical all have entered the rocket field with low-cost solid propellants; this indicates a healthy scene for RATO. A newcomer to the field, American Rocket Company, has recently announced an all-ammonium-nitrate propellant with a specific impulse of around 200 sec suitable for RATO and with an "essentially smokeless exhaust."

Aerojet, however, has taken a new tack on the problem of RATO to supplement their solid propellant rocket. At a recent public demonstration at Edwards AFB, California, a B-47 took off, using a high-thrust liquid propellant RATO system. The Aerojet unit is retractable. Thus, the present picture indicates a RATO race shaping up.

Research. Much of today's rocket progress still lies in the research stage. Aerojet, for example, with its familiar Aerobee research rocket is attempting to extend this missile's altitude capabilities to over 130 miles. A new altitude record for the Aerobee was just set at 90 miles over White Sands. The Aerobee, propelled by a bifuel system, is a



Aerojet-General

Aerobee with booster

free flight rocket which is launched and receives its initial guidance from a 150-ft tower. After this, fixed-fins provide guidance. Carrying a nominal payload of 150 lb, the Aerobee is 20 ft long and has a diameter of 15 in. A solid propellant booster adds another 6 ft to its length.

The Navy's Martin Viking is turning into a high-altitude workhorse to replace the old V-2's. Viking No. 10 attained an altitude of 136 miles, while No. 11 attained a new single-stage altitude record of 158 miles. The Viking is being groomed for an eventual 200-mile shot. Another rocket research aspect is the rocket-propelled sled at Holloman AFB, New Mexico, where Col. Stapp of the USAF attained a speed of 421 mph. With eventual supersonic runs, Col. Stapp previously has been subjected to accelerations as high as 45 g's without harmful effects.

The Navy announced that two of its helicopters under development, rocket-propelled, have been flown safely. Tiny rocket motors, weighing 1 lb and developing 16-lb thrust, are located at the blade tips. The liquid monofuel is fed to each rocket engine from a single fuel tank by fuel lines running through the length of each rotor blade. Propellant feed is by high-pressure inert gas. The first U. S. rocket-powered helicopter, the RH-1 made by the Rotor-Craft Corp., Glendale, Calif., uses two of the thumb-sized rockets and has been under development for four years. The Kellett KH-15, also powered by these units, has also been successful in tests.

White Sands Proving Ground

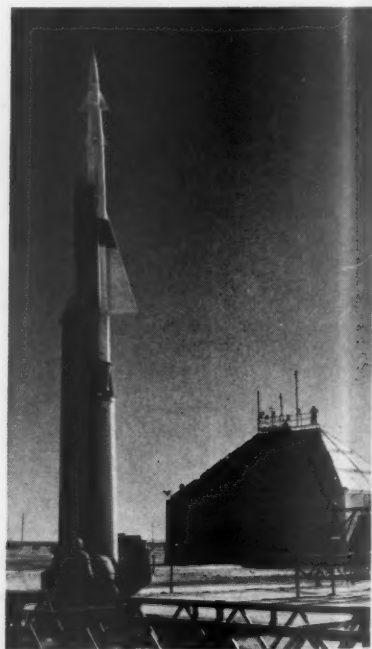
WHITE Sands Proving Ground, Las Cruces, N. Mex., under command of the Chief of Ordnance, is the principal U. S. Army Ordnance Corps installation for the execution of all technical and engineering responsibilities associated with the flight testing of guided missiles and rockets. WSPG is also concerned with research and development functions and for unit training of personnel.



General Electric

Aerial view of White Sands Proving Ground

Although WSPG is an Ordnance activity, it is unique in that the Army, Navy, Air Force, Marine Corps, industrial and academic institutions are represented here. The primary job is the testing of rockets and guided missiles, target drones, etc., of medium range. Located between the San Andreas and Sacramento Mountain ranges, it is about 50 miles north of El Paso, Tex., in the treeless, sandy, flat, sparsely populated White Sands Desert. Photo shows an aerial view of the base which was opened about 9 years ago on July 9, 1945. One of the first major construction jobs at WSPG was the familiar blockhouse, the nerve center of a missile launching. This structure, with 10-ft thick walls and a solid reinforced-concrete pyramidal roof with a maximum thickness of 15-ft has witnessed many firings. Photo shows the Nike missile poised on a launcher before the famous blockhouse. The



U. S. Army

Sleek Nike in front of blockhouse

first rocket tested here, however, was the American-designed "Tiny Tim" on Sept. 26, 1945. Another construction job was the now-familiar gantry crane developed for servicing large rockets.

Among the most recent improvements at WSPG is a two-story laboratory, completely air-conditioned and equipped for individual room-temperature selection. To make the laboratory dust-free, windows were eliminated and entrance



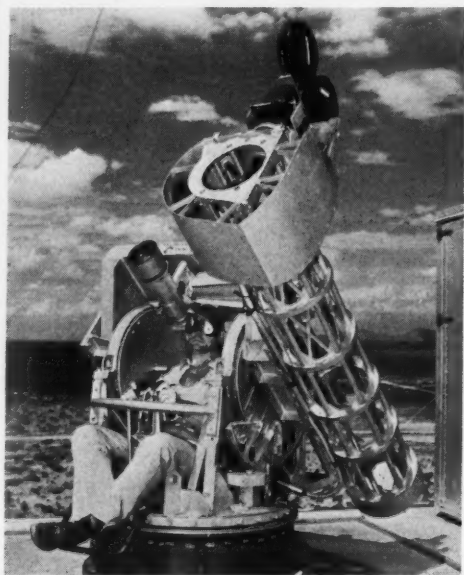
U. S. Army Ordnance

500,000-lb static test stand in operation

is gained through an air-lock. The basement contains over 13,000 sq ft of floor area and provides air-conditioned film storage, optical testing, machine shop, battery conditioning, and other service facilities. Four suites of laboratories are located on the first floor. A ballistics research laboratory is on the second floor. The roof is utilized as a line-of-sight laboratory for firing and instrumentation control points.

In addition to the flight test facilities, WSPG has two static test stands with thrust capabilities of 100,000 and 500,000 lb; photo shows a firing being conducted in the latter stand.

WSPG carries out its classified activities in the testing of guided missiles by means of technical groups. The Technical Engineering Branch provides fundamental engineering and planning services. The Range Control Branch has control of and schedules missile firings. The Electronics and Safety Branch is concerned with the protection of lives and property and helps keep missiles on the range by the use of beacons and safety devices. The Shops and Services Branch is equipped to handle machine shop services and to do field

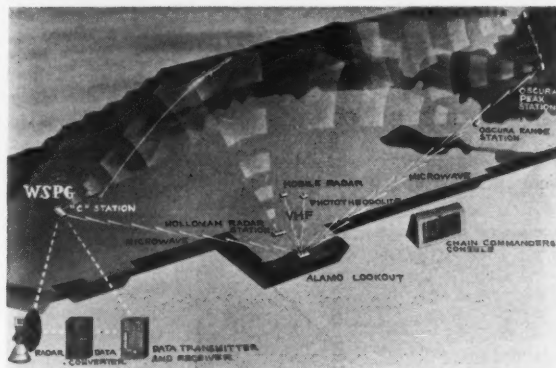


U. S. Army Ordnance

Missile tracking telescope

construction and maintenance. The Flight Determination Laboratory plans and provides instrumentation and techniques (radar, telemetry, photography, etc.) for data gathering on missiles from time of launch to time of intercept or impact. Photo shows a missile-tracking telescope developed at WSPG. The Environmental Laboratories plan and conduct ground tests of major units and components of guided missile systems. In addition it provides calibration and repair services for electronic and mechanical components.

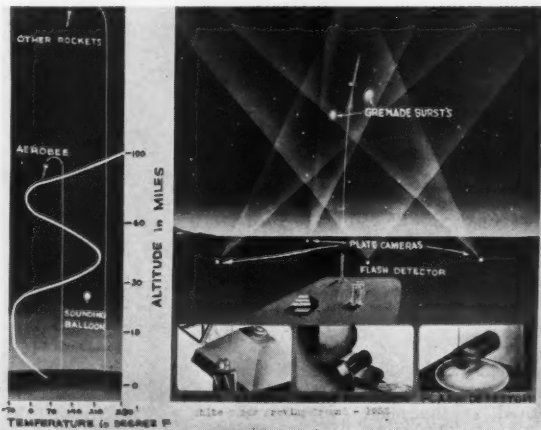
A chain radar system (photo) is used to track missiles on the



U. S. Army Ordnance

Chain radar system at WSPG

range. In each radar installation, equipment is provided for converting the missile's co-ordinate position in space to electrical quantities; the electrical information is then placed on a transmission bus and is used for positioning other radar sets in the chain system, as well as the positioning of phototherodolites, etc. Only one station can collect positioning information from the missile, but any one can take over. Consoles are located at WSPG and Holloman Air Force Base which display the activity of the stations and where it can be decided to put different stations in control of the chain system, depending on the quality of information being gathered by each during operation.



U. S. Army Ordnance

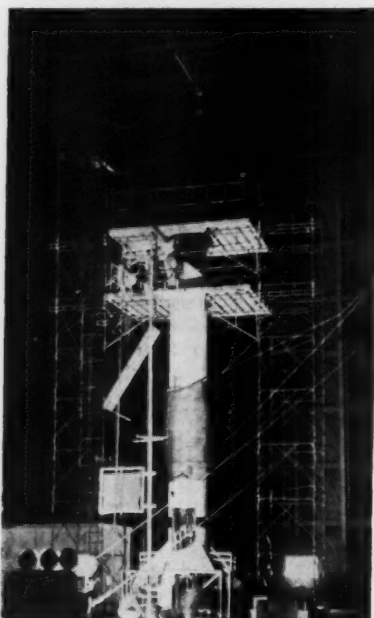
Upper atmosphere temperature determination

A unique method of upper-atmosphere temperature determination (photo) was pioneered at WSPG. Aerobee rockets have been fired containing "grenade" explosive charges preset to be ejected and exploded at certain intervals. The flashes of the ejected grenades are recorded on the ground by four plate cameras and a flash detector. A triangulation from the plate camera gives the location of burst, and the flash detector records the exact times of each burst. An array of microphones picks up the sound explosion when it reaches the

Viking Firing at White Sands



1 Viking on wheels . . . Looking no more glamorous than an overgrown stovepipe, the main section of Viking no. 10 is towed to its launching area

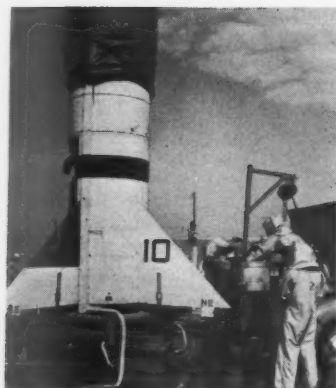
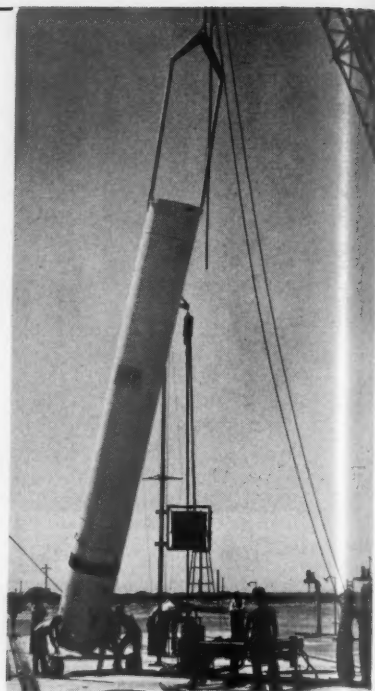


3 Lights ablaze . . . Throughout the long night on the gantry crane, crews labor to put it in condition for its trip into the upper atmosphere

5 Fueling . . . The launching area is cleared as the main fuel tanks are filled with hundreds of gallons of alcohol

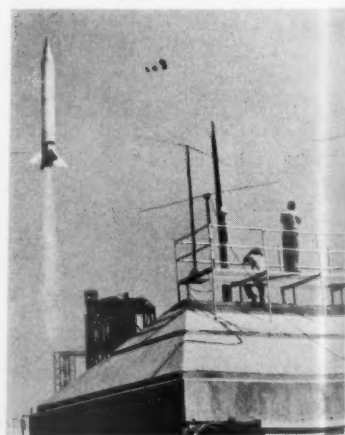


2 Standing up . . . It goes into the gantry frame to have its fitting for nose and tail



4 Rocket garbed . . . Members of the fueling crew pump hydrogen peroxide into the rocket. The high strength peroxide is used to operate the turbopumps

6 Missile away . . . The rocket thrusts toward the upper atmosphere. This Viking was launched on May 10 and attained an altitude of 136 miles. The telemetered data recorded on oscillograms and wreckage recovered from the impact area are analyzed after the flight by engineers to obtain information on the performance of the rocket in flight and answers to some of the mysteries of the upper atmosphere



ground and records it on a sound ranging recorder. By determining the distance between bursts from the plate camera data and dividing by the difference in time it takes the sound to reach the ground, the velocity of sound between bursts is established. This increase or decrease in velocity is proportional to the increase or decrease in temperature. The curve at the left in photo gives an indication of the present knowledge of temperature in the upper atmosphere, which is constantly being added to and extended.

The launching techniques employed in connection with a recent firing are illustrated on the opposite page in the picture story on the Viking.

The elaborate operations involved in current rocket testing require precise coordination and many man-hours of work. White Sands Proving Grounds has fostered such operations in the transition from a primitive art to a modern science.

Upper Atmosphere Research

THE Navy announced that it had conducted a new series of tests using Skyhook balloons early this year in conjunction with the Atomic Energy Commission in cosmic-ray research.

DAILY temperatures actually fluctuate less in the ozone layer some 12 to 18 miles above the earth than at the earth's surface, say New York University scientists. The work at NYU consists of the collection and interpretation of data from rockets and balloons and is sponsored by the U.S. Air Force.

A MAJOR international geophysical research program, involving co-operation of about 30 nations, is being planned for 1957 and 1958. The National Academy of Sciences announced that upper atmosphere rocket studies will be among the fields in the program.

LOCKHEED Aircraft Corporation announced that 381 of its employees had undergone explosive decompression.

The pressure release produced an abrupt noise, split-second wind blast, and fog, but physical effects to personnel were negligible. While the decompression tests were simulated under 25,000-ft altitude conditions, it was explained that increased safeguards against decompression must be provided at higher altitudes.

Students Win Guggenheim Awards for Jet Studies

THE Daniel and Florence Guggenheim Foundation announced Fellowships for advanced studies at Princeton University and the California Institute of Technology. The awards are granted each year to outstanding students showing promise in the field of rocket and jet propulsion. The purpose of the program is to provide America with young men who will be able to lead future developments in the field with particular emphasis on peacetime uses.

Awarded the grants for the 1954-1955 year at Princeton University are: Robert Hirschkron, of Lynn, Mass., B.Sc. in mechanical engineering; Paul Lieberman, of Brooklyn, N. Y., B.Sc. in aeronautical engineering; Sau-Hai Lam, of Bronx, N. Y., B.Sc. in aeronautical engineering; Dwight A. Mahaffy, of Wichita Falls, Tex., B.Sc. in aeronautical engineering; Edward S. Wilson, of Xenia, Ohio, B.Sc. in aeronautical engineering; and Guy C. Wooten, of Monterey, Calif., B.Sc. in aeronautical engineering. Awards were renewed for Sinclair M. Scala and Andrew F. Burke.

Receiving the grants for study at CalTech during the 1954-1955 academic year are: Jack L. Kerrebrock, of Pasadena, Calif., M.S. in mechanical engineering; Sedat Serdengecti, of Izmit, Turkey, M.S. in mechanical engineering. Guggenheim Jet Propulsion Fellows currently at CalTech whose grants have been renewed for another year are: David M. Benson, Saul Feldman, and Robert J. Hartlieb.

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Aircraft

A NEW view of the Navy's latest single jet, sweptwing, carrier-based fighter, the XF3H-1 Demon, is shown below. The Demon, being produced by McDonnell Aircraft Corp., is currently undergoing flight tests.



U. S. Navy

XF3H-1 Demon, Navy carrier fighter

DOUGLAS Aircraft Company is reported to be developing a jet transport capable of carrying 60-100 passengers at a 574-mph cruise speed up to a range of 1200 miles. The craft, called the DC-8, is also being designed for an alternate range of 2400 miles. The DC-8 is essentially a swept-wing version of the DC-7 and is powered by 4 underslung podded turbojet engines.

LOCKHEED Aircraft Corporation also is said to be working on a jet transport. The craft, known as the L-193, has a load capability of 80-100 passengers, and is designed for a range of 3500 mi at a cruising speed of 564 mph. The L-193 features four turbojet engines buried in a lateral row beneath the fuselage midway between the wings. Construction is said to await the advent of more powerful engines.

CARAVELLE is the name for a new French-designed twin-turbojet, medium-range transport. Over 70 passengers are to be carried in the ship which has a cruising speed of 479 mph and a range of 1675 nautical miles. Two Rolls-Royce Avon R.A. 16 turbojets are mounted in pods on the fuselage near the tail section, leaving the swept wings free of protuberances.

ANOTHER French turbojet-powered transport is the Hurel-Dubois HD-45. Also powered by Rolls-Royce Avon R.A. 16 engines, the plane is designed to carry 70-80 passengers at a cruising speed of 425 mph. The 90,000-lb craft has a span of 150 ft, a length of 96 ft, and a height of 30 ft.

Facilities

COMPLETED at Eglin AFB, Florida, is a new air-to-ground rocket test range. It was also reported that a rocket-sled facility is also to be placed in operation. Rockets are to be fired from the rocket-propelled sled to simulate the firing of rockets under high-speed flight conditions.

SOUTHWEST Research Institute of San Antonio, Texas, lists several rocket projects among its research activities. Included are projects in: development of high-energy inorganic reductants, economic manufacture of oxidizers such as peroxides and superoxides, a fundamental study of the ignition of propellants and explosives, oil-well applications of propellants, and a study of the factors entering into the launching

and accuracy of rockets. It is stated that a large portion of the high-energy program is nonmilitary and that industrial and commercial applications of rockets are being sought.

DETAILED reports of research conducted by "Project Squid" have recently been made available. Project Squid is a research program, fundamental in nature, dealing with combustion, heat transfer, and fluid mechanics with particular emphasis to applications in rockets, missiles, and jet engines. Taking its name from the jet-propelled squid, the project was begun in 1946 by the Navy Bureau of Aeronautics. The program, then as now, was directed by Princeton University. Originally five universities participated, but now the following organizations are a part of the project: Brooklyn Poly, CalTech, Dartmouth, University of Delaware, Johns Hopkins, M.I.T., University of Michigan, Northwestern, Princeton, Purdue, Atlantic Research Corp., Experiment, Inc., Cornell Aeronautical Laboratory, and the U.S. Bureau of Mines. Research grants total about \$750,000 per year and come from research groups of the Air Force, Army, and Navy.

New Astronautical Publications

UNDER the aegis of the International Astronautical Federation, a new periodical, *Acta Astronautica*, is to be published. The work will present papers in the many scientific fields lying between aeronautics and astronautics. Apart from this project, a microfilm book series, "Biblioteca Astronautica," will be published at irregular intervals. The latter will present longer original works, previous works no longer in print, and summaries of various subjects. Dr. Eugen Sänger will edit the works which are to be published by R. Oldenbourg Verlag, München, Germany.

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White Sands Tour to Feature Fall Meeting

APPROVAL has been received for a complete tour of unclassified areas of White Sands Proving Ground, to be conducted by the U. S. Army Ordnance Corps on the last day of the Sept. 22-24 Fall Meeting.

It has also been announced that Brig. Gen. W. L. Bell, the new Commanding General of WSPG, will be the principal speaker at the banquet to be held on Thursday evening.

The White Sands tour, which will include range installations, test stands, instrumentation and environmental laboratories, will also afford a chance to see static and flight firings of missiles normally scheduled for testing. Friday, according to reports, is usually a heavy day for such firings.

Tentatively scheduled for Wednesday evening of the meeting is a trip to Fort Bliss, Tex., where the U. S. Army Anti-Aircraft and Guided Missile School will stage a demonstration to include erection, fueling, and mock firing of several of the Army's latest guided missile weapons systems—probably including a Corporal and an Honest John.

Several changes have been made in the program of technical sessions, which will be held at the Hilton Hotel in El Paso. The full program is now as follows:

WEDNESDAY, SEPTEMBER 22

9:00 a.m. Session I

Instrumentation

Chairman: W. J. Baisley, North American Aviation, Inc.

Generation of High Gas Pressure Through Hydraulics, by H. Halperin, Greer Hydraulics, Brooklyn, N. Y.

Test Procedure vs. Test Instruments, by Robert Lucas, Bell Aircraft Co., Holloman AFB, N. Mex.

Use of Rockets for Cosmic Ray Research, by R. E. McDaniel, WSPG.

2:30 p.m. Session II

Environment

Chairman: W. J. Baisley, North American Aviation, Inc.

Vice-Chairman: H. Diem, North American Aviation, Inc.

Effects of Sub-Gravity on Animal Performance, by D. G. Simons, Holloman Air Development Center, Holloman AFB, N. Mex.

Pittsburgh Meeting on "Materials" Accents Heat Problem in Engines

HEAT-RESISTING properties of available materials continue to be the major limitation in the development of desirable efficiency in turbojet engines for aircraft, according to AMERICAN ROCKET SOCIETY papers presented on June 24 at the semi-annual meeting of the American Society of Mechanical Engineers in Pittsburgh.

One of the speakers, G. A. Fritzlen of Raynes Stellite Co., Kokomo, Ind., said

Free Flight Determination in Missile Environment Generated by Solid Propellant Motors, by H. Gumbel, U. S. Naval Air Missile Test Center, Point Mugu, Calif.

Rocket Sleds at Biological Test Vehicles, by J. P. Stapp, Holloman Air Development Center, Holloman AFB, N. Mex.

Effects of Environment on Guidance, author unnamed, WSPG.

7:00 p.m. Tour to Fort Bliss

THURSDAY, SEPTEMBER 23

9:00 a.m. Session III

Guidance

Chairman: E. E. Francisco, Jr., WSPG.

Vice-Chairman: E. L. Brown, WSPG.

Radar and Guided Missiles, by W. Hiltz, Holloman Air Development Center, Holloman AFB, N. Mex.

Rocket Motor Design Principles, by Robert Gordon, Aerojet-General Corp., Azusa, Calif.

Reliability Concepts and Methods in the Evaluation and Improvement of Guided Missile Systems, by J. R. Duffitt, WSPG.

Ascent of Orbital Vehicles and Mechanics of Descent of Orbital Vehicles, by Kraft A. Ehricke, Bell Aircraft Co., Buffalo, N. Y.

2:30 p.m. Session IV

Evaluation

Chairman: H. S. Seifert, Jet Propulsion Laboratory, California Institute of Technology.

General Considerations in Missile Evaluation, by R. Weller, U. S. Naval Air Missile Test Center, Point Mugu, Calif.

System Simulations for Missile Evaluation, by John H. McLeod, Jr., U. S. Naval Air Missile Test Center, Point Mugu, Calif.

Reliability in Guided Missiles, by R. P. Haviland, General Electric Company, Key West, Fla.

8:00 p.m. Banquet

Chairman: A. G. Haley, President ARS.

Vice-Chairman: R. W. Porter, Vice-President, ARS.

Speaker: Brig. Gen. W. L. Bell, Commanding General, WSPG.

FRIDAY, SEPTEMBER 24

7:00 a.m. All-day Tour of WSPG

National Headquarters Moves

On August 5 the ARS secretariat moved from the Engineering Societies Building, 29 West 39th Street, to new offices at 500 Fifth Avenue. The move was necessitated by a requirement for more space, there being no additional room available for expansion in the old building.

Members visiting New York are cordially invited to inspect the new quarters.

of temperature and stress, research scientists are continuing their hunt for materials having better properties at high temperatures.

Their studies have been extended to materials having different base compositions than those metal alloys which have led to present-day successes. These materials include metal-ceramic mixtures, refractory oxides, intermetallic compounds, molybdenum base alloys, tungsten base alloys, and chromium base alloys.

Mr. Fritzlen named four materials now being used extensively in jet engines. These materials contain 20 to 62 per cent cobalt, large percentages of chromium and nickel and, with one exception, comparatively small proportions of iron. Molybdenum, tungsten, columbium, and tantalum are also included in some of these alloys. Detailed material studies are also under way now to determine maximum performance from a jet engine assembly in which present known materials are used in the hope that operating temperatures can be raised approximately 100 F with safety.

For other components of aircraft gas turbines, titanium alloys are being used to such an extent that fabrication methods for these materials have been developed in an unprecedented manner in recent years. Arnold S. Rose, I-T-E Circuit Breaker Company, Philadelphia, Pa., reviewed the present status of methods used in forming, spinning, forging, and welding titanium, and indicated that innovations in hot forming and spinning methods and in the use of a helium-filled welding chamber for fusion welding of titanium base alloys, have been especially useful for pilot production of aircraft parts.

He said that modification and simplification can be expected when large-scale production of such parts is required. The flow of titanium under the drop hammer was said to be like that of stainless steel of the AISI 300 series. Filling of the dies was reported to be exceptionally good.

In both forming and spinning operations an initial temperature of 1300 F is used. During and at the conclusion of a spinning operation the temperature may have dropped to 800 or even 600 F.

The use of a helium-filled welding chamber for fusion welding resulted from a basic

requirement that the molten metal be shielded from contact with air. Resistance welding can be done in air because the parent metals protect the molten nugget at the joint interface. A tendency to excessive penetration in resistance welds may be limited by proper welder setups.

The possibilities for plastics as materials for liquid-propellant rocket components were explored by Paul M. Terlizzi, U. S. Naval Air Rocket Test Station, Lake Denmark, Dover, N. J. Up to the present, only fluorocarbon plastics (polytrifluorochloroethylene) have been used in the liquid propellant field because of their excellent compatibility with corrosive propellants and their retention of this and other properties at low and high temperatures. Since many applications do not require maximum compatibility characteristics, however, lower cost plastics may be applied, he said.

Mr. Terlizzi's opinion was that recent improvements in the properties of plastic materials, their fabrication and design, should assure them of uses in this field. Other important considerations in selection of plastics are weight reduction, pressure limits, design details, and corrosion protection. Possible applications were said to be pressurizing lines, propellant tanks and lines, pressurizing regulators, containers, filters, protective clothing for personnel, and coatings for metal surfaces and wire. The most promise in solving the corrosion problem of containers appears to be the use of a pinhole-free, loose-fitting plastic bag in a steel container. The use of reinforced plastics, particularly those incorporating glass fiber, is considered to be applicable also, because of their comparatively low weight.

Fundamental principles of heat transfer in fibrous insulations were explained by Paul Greebler, Johns-Manville Research Center, Manville, N. J., with respect to the contributions of each mechanism of heat transfer as it applies to high temperature service in aircraft. His conclusions were based on analysis of experimental conductivity data at various mean temperatures and densities.

Radiation and air conduction were found to account for nearly all of the conductivity at higher temperatures. The insulating material is described as a felt composed of high-silica or alumino-silica fibers enclosed in metallic foils. Fiber diameters range from one to ten microns and the felt is highly porous, with air spaces occupying more than 90 per cent of the total insulating volume. The fibers resist softening or devitrifying to temperatures above 2000 F.

Conductivity attributable to radiation was found to vary approximately as the cube of the absolute temperature, linearly with the effective fiber diameter, and inversely as the density of the insulation. Conductivity attributable to air conduction was found to depend only on temperature and cannot be controlled by varying the physical properties of the insulation.

Thermal conductance was reduced in tests by increasing either thickness or density, the former being more efficient from the standpoint of minimum insulation weight. An internal reflective foil did not appreciably reduce conductance. If the insulation is used in series with an air gap,

the emissivity of the foil may have an appreciable effect on over-all transmittance. In one instance an air gap contributed about 40 per cent of the total thermal resistance when the foil emissivity was 0.3.

When there is sufficient space for a fairly thick insulation in jet propelled aircraft, a low thermal diffusivity of the insulation can provide adequate thermal protection, even though the heat capacity of the insulated component may be very low. The heat capacity of a thin insulation, which may be required when space is limited, may generally be neglected. Conductance is then the only thermal property retarding heat transfer.

In other papers presented at the meeting, G. B. Brown of Tube Reducing Corp., Wallington, N. J., described methods used for "rocking" seamless tubing into strong-walled rocket casings; and E. L. Hart of Marotta Valve Co., Boonton, N. J., discussed the problems of sealing valves which handle propellants. Brown described machinery now available which would permit the cold reduction of ballistic and booster rocket casings up to 18-in. diameter.

Hart said that aircraft and missile cavity temperatures are rising to the point where, in some cases, the ambient rather than line fluid temperatures have become the governing values. He stated that his company has been asked to quote on seals for ambient temperatures too high for "O" rings made of any currently available elastomer.

Six New Corporate Members

Six firms active in rocket and jet propulsion work or related fields have recently become Corporate Members of ARS. They include:

American Machine & Foundry Co., New York—Doing development work on mono-propellants, rockets and guided missile systems in its various plants and research laboratories.

Chance Vought Aircraft, Inc., Dallas, Tex.—Developer of the Regulus turbojet-powered surface-to-surface missile and the F7U-3 Cutlass. The company recently became independent of United Aircraft Corp.

Republic Aviation Corp., Farmingdale, N. Y.—Manufacturers of the F84F. The company's Guided Missiles Division recently moved from New York City to Hicksville, L. I.

Bendix Aviation Corp., Eclipse-Pioneer Div., Teterboro, N. J.—Maker of guided missiles (including the surface-to-air Loki, powered by a solid propellant rocket), rockets, launchers, fuses and other accessories.

Western Gear Works, Lynwood, Calif.—Producer of actuating mechanisms for rocket guide-vanes, for missile guidance and ground control systems, and for telemetering equipment.

Food Machinery & Chemical Corp., San Jose Calif.—Parent company of Buffalo Electro-Chemical Co., Buffalo, N. Y., producers of hydrogen peroxide. Other divisions of the company are engaged in development work related to the rocket field.

The complete list of Corporate Members now includes:

Aerjet-General Corporation, Azusa, Calif.

Aeronautical Digest Publishing Co., Washington, D. C.

American Machine & Foundry Co., New York, N. Y.

Bell Aircraft Corporation, Buffalo, N. Y.

Bell Telephone Laboratories, Inc., New York, N. Y.

Chance Vought Aircraft, Inc., Dallas, Tex.

Curtiss-Wright Corporation, Propeller Div., Caldwell, N. J.

Douglas Aircraft Company, Inc., Santa Monica, Calif.

Eclipse-Pioneer Division, Bendix Aviation Corporation, Teterboro, N. J.

Food Machinery and Chemical Corporation, San Jose, Calif.

Genisco, Inc., Los Angeles, Calif.

Greer Hydraulics, Inc., Brooklyn, N. Y.

Harvey Machine Co., Inc., Torrance, Calif.

Haynes Stellite Co., Kokomo, Ind.

Kearfott Co., Clifton, N. J.

Linde Air Products Co., New York, N. Y.

Lockheed Aircraft Corporation, Burbank, Calif.

North American Aviation, Inc., Los Angeles, Calif.

Reaction Motors, Inc., Rockaway, N. J.

Republic Aviation Corporation, Farmingdale, N. Y.

Laurance S. Rockefeller, New York, N. Y.

Thiokol Corporation, Trenton, N. J.

United Aircraft Corporation, East Hartford, Conn.

Western Gear Works, Lynwood, Calif.

Two New Awards Named

THE Board of Directors has approved the establishment of two new ARS awards to be presented for the first time this year:

1 The James H. Wyld Memorial Award—sponsored by Reaction Motors, Inc.

2 The American Rocket Society Astronautics Award—endowed by Andrew G. Haley.

These two awards were announced in the last issue of JET PROPULSION, but the names were not then established. The first new award is named after James H. Wyld, former president of the ARS and formerly associated with Reaction Motors, Inc. His early contributions to the technology of liquid propellant rockets, particularly his design of a regeneratively cooled rocket motor, are some of the outstanding achievements that are to be commemorated by this award. Mr. Wyld died in the winter of 1953 while still active in the rocket and atomic energy fields.

The award in the field of astronautics was suggested by our president, A. G. Haley, who also generously endowed this award. The sponsor has in the past been very active in stimulating interest in this field and he hopes that this award, to be given for outstanding accomplishment in astronautics, will ferment new thought in this field.



The Viking area is inspected by Maryland Section at The Glenn L. Martin plant (left). At right, E. T. Munnell, Viking Project Engineer at Martin, speaks about the famed research rocket before the group. Seated is J. R. Youngquist, who was chairman of the Section meeting.



Section Doings

Alabama. Joseph Wiggins of Thiokol Corp., Redstone Arsenal, is the new president succeeding George Henderson. An active program is being planned for 1954-1955.

Arizona. Robert H. Hansen replaces Anthony Tocco as Section president. Tocco has been transferred to Hughes Aircraft's Culver City plant.

Maryland. A meeting was held at the Glenn L. Martin plant on June 22 and new officers were elected. They are: William G. Purdy, Operations Manager of the Viking Project at Martin, president; Sears Williams, Martin, vice-president; John DeNike, Martin, secretary; and W. J. Crotty, Jr., Miller Metal Products, treasurer. On the Board are R. B. Chapman III, and Joel M. Jacobson of Aircraft Armaments, and J. L. Burridge, Ivan E. Tuhy, and J. R. Youngquist of Martin.

After the installation of officers, E. T. Munnell, Viking Project Engineer of Martin, talked on "Some Interesting Aspects of the Viking Rocket" (above), and films on the #10 and #11 Viking firings were shown by Mr. Youngquist.

Dinner was served by the Martin company to the 70 members and guests who were also given a tour of the Viking area in the plant.

Sears Williams has been appointed Section representative to the committee planning the Spring ASME-ARS meeting to be held in Baltimore next April.

National Capital. Open House was held at the Naval Observatory for ARS members and guests on June 11. Lectures on the stars, planets, and constellations were given and two telescopes were available for viewing.

New Mexico-West Texas. The film "Destination Moon" was shown at the June 24th meeting and refreshments were served. The second issue of *Missile Away* was published in June and carried,

Twin Cities, Central Texas, and Southern Ohio Sections Formed

By-laws for three new Sections have been submitted to the National Board recently, and several other Sections are in the process of forming.

About to be chartered are the Twin Cities Section at Minneapolis-St. Paul, Minn.; the Central Texas Section at Waco, Tex.; and the Southern Ohio Section at Cincinnati-Dayton.

Other Sections are forming at San Diego, Seattle, Eastern Massachusetts, Wichita, and Philadelphia.

among other excellent articles, a piece by Lt. Col. J. P. Stapp, renowned for his experiments on the rocket-powered test sleds, on "Crash Survival." A substan-

tial amount of local and national advertising was interspersed among the interesting pages.

New York. One of the most interesting and informative meetings of the year was held on June 25, featuring a panel discussion on "The Administration of a Technical Project." Details will be included in the November-December issue.

Northeastern New York. New officers recently elected are: Kurt Berman, president; J. C. Hoffman, vice-president; W. S. Kleczak, treasurer; E. I. Finger, secretary. On the Board of Directors are: T. M. Pettey, A. B. Brown, and A. H. Fox. All are from General Electric except Dr. Fox, who is with Union College.

Southern California. A confidential field trip to the U. S. Naval Air Missile



St. Louis Section convenes with President Haley at organizational meeting. In front row are Elzey M. Roberts, Jr., vice-president; Norton B. Moore, president; Mr. Haley; and James J. Mazzoni, secretary. Standing are Directors Edwin C. Dow, R. L. Schapker, and F. T. Stark



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Convair's widely-publicized XFV-1... the new Convair delta wing vertical take-off plane designed, engineered and built in San Diego.

Test Center at Point Mugu took place on July 21.

The June 15 issue of the Section "Newsletter" included, in addition to a thoughtful editorial by President H. S. Seifert on "The Relation Between the U. S. Government and the American Rocket Society," a fine news section on developments in the rocket and missile field, plus "The Intercom," a page devoted to remarks about Section personalities and area industry.

On June 9 President Haley met with the Board of Directors concerning general matters relating to the Section's position within the framework of the national organization.

Northern California. A dinner meeting with President Haley was held by the officers and Board of Directors in June in San Mateo.

ARS SECTION PRESIDENTS

Alabama	Joseph Wiggles Redstone Arsenal
Arizona	Robert H. Hansen Hughes Aircraft Co.
Chicago	Kenneth H. Jacobs American Machine & Foundry Co.
Cleveland-Akron	John Sleep Lewis Flight Prop. Lab., NACA
Detroit	Laurence M. Ball Chrysler Corp.
Florida	K. K. McDaniel Boeing Airplane Co.
Indiana	A. R. Graham Purdue University
Maryland	William G. Purdy Glenn L. Martin Co.
National Capital	J. R. Patton, Jr. Office of Naval Research
New Mexico- West Texas	Frank L. Koen, Jr. White Sands Proving Ground
New York	Michael J. Samek American Electro-Metal Corp.
Niagara Frontier	W. Sprattling Bell Aircraft Corp.
Northeastern New York	Kurt Berman General Electric Co.
Northern California	William J. Barr Detroit Controls Corp.
Princeton Group	John Scott Princeton University
Southern California	H. S. Seifert Calif. Inst. of Tech.

1955 Roster Being Readied

PUBLICATION of the 1955 ARS Roster is expected to take place in January. All members are urged to cooperate in its preparation by promptly filling out and returning the questionnaire postcards which are being mailed from the National Office. Any person not receiving the questionnaire is requested to contact the Secretary.

Book Reviews

C. F. Warner, Purdue University, Associate Editor

The Physics of the Stratosphere, by R. M. Goody, Cambridge University Press, New York, N. Y., 1954. \$5.

Reviewed by N. C. GERSON
Air Force Cambridge Research Center

"The Physics of the Stratosphere" lifts man out of his gross preoccupation with the lowest two meters of atmosphere and gradually wafts him higher and higher into the exciting and fascinating outer shells of the planet. This well-written, ably presented text, suitable for an introductory course on the topic, everywhere negates Halley's early statement, "The theory of the air seems now to be perfectly well understood..."

Five topics are discussed: temperature, composition, ozone, winds and turbulence, and thermal equilibrium. The various atmospheric properties and factors are carefully interrelated among the chapters so as to give the reader a comprehensive and unified picture of the earth's gaseous envelope below the ionosphere. As one of the Cambridge Monographs of Physics, the volume continues, both in format and content, the tradition of concise but comprehensive treatments in selected fields of physics. In this volume over half the references were published in 1946 or later.

The author avoids becoming embroiled in the various nomenclatures already proposed by defining his own: in line with general agreement, the lowest atmospheric shell is the troposphere; the next lowest is the stratosphere, which by his definition, extends to 80 km. Some explanation is given of the various indirect methods utilized in deducing the properties of the higher atmosphere. For comparison, corresponding results obtained by means of direct experiments aboard rockets are also included. Average characteristics of the Aerobee and V-2 rockets are mentioned, and some of the difficulties inherent in rocket investigations—both in the experimentation and in the interpretation of the recorded data—are emphasized.

In discussing temperature, the author describes techniques involved in obtaining temperatures from meteor observations, compressional wave propagation, spectrograms of the airglow, and, of course, directly with balloon and rocket-borne instruments. For completeness, an indication of the possible temperature distribution in the ionosphere (80–400 km) is also presented.

Careful treatments are given to both the ozone problem and the difficult field of thermal equilibrium, with adequate descriptions of both the theory and the observational methods. In the case of ozone, the diurnal, seasonal, and latitudinal variations and the relationship to the local meteorological situation are lucidly presented.

In dealing with composition the author emphasizes the water vapor-altitude re-

lationship perhaps at the expense of discussing some other constituents. Although the role of CO_2 , NO_2 , CH_4 , and the rare gases is described, an improvement would result if some space were devoted to CO , HDO , etc. More attention could have been given to the techniques of examining the solar infrared absorption spectrum and to the method of detecting the minor atmospheric constituents. In this connection, it would have been very interesting if an indication had been given of the isotopic concentrations of the permanent atmospheric gases and the increases to be expected with each atomic detonation.

The summary of information on high altitude winds is valuable for many reasons, but undoubtedly this section will require considerable revision shortly. The general extrapolations on possible wind systems must be accepted with caution. More attention could have been directed to the probable circulation system over the planet as a whole at selected higher altitudes; however, this topic is also in a rapidly advancing state.

In general, some topics are absent which could have appreciably added to the value of the book even if treated in a very abbreviated manner. The physics of clouds and precipitation is wholly ignored, and the relationship of temperature and humidity lapse rates to superrefractive conditions is absent. Recent advances in solar absorption spectroscopy have been omitted, and the difficulties inherent in the general three-dimensional diffusion problem, even for the ionized atmosphere, is scarcely touched. The importance of light scattering as a stratospheric probe is but briefly mentioned, while a review of solar-weather relationships is lacking.

On the whole, however, and to his credit, R. M. Goody has organized a well-balanced text on an atmospheric region of increasing importance. After a discussion of the currently available information, he provides a very welcome critical and objective inspection of the results.

Applied Nuclear Physics, Second Edition, by E. C. Pollard and W. L. Davidson, John Wiley & Sons, Inc., New York, N. Y., 1951, 352 pp. \$5.

Reviewed by LEONARD M. GOLDMAN
Princeton University

Ernest Pollard, Professor of Biophysics at Yale University, and William Davidson, Director of Research for the Goodrich Rubber Company, have written an informative introduction to nuclear physics. The book is not directed toward the specialists in nuclear physics but rather, to quote the authors, "to the growing army of scientists and engineers who, though not necessarily versed in the language of physics, are using the products of nuclear physics."

This second edition has been modernized by considerable rewriting of the material in the original edition and by the adding of chapters on such subjects as nuclear chain reactions and pile theory. It would be an exaggeration to say that the book was completely up to date since it is virtually impossible to keep up with a field which is changing so rapidly.

This reviewer finds the title a little misleading, as only a small fraction of the book is concerned with applications. One expecting to find plans for a nuclear power reactor will be disappointed. It is a good nonmathematical survey of the field useful to one desiring to become acquainted with the language and phenomenology of nuclear physics. For one attempting to solve a specific problem in nuclear physics the book lacks sufficient detail to be particularly useful.

Ultra High Frequency Propagation, by H. R. Reed and C. M. Russell, John Wiley & Sons, Inc., New York, N. Y., 1953, 562 pp. \$9.50.

Reviewed by R. STEVENS
California Institute of Technology
Jet Propulsion Laboratory

Although written in textbook fashion with extensive problem sets, this book is actually a comprehensive handbook of UHF-VHF radio propagation. It contains a wealth of readily accessible reference material in graph and tabular form in addition to an explanation of fundamentals.

The book adequately covers the current field of UHF-VHF propagation including reference to the question of VHF propagation at great distances. Its approach is largely from the point of view of aircraft communications, although the results derived can be applied to other UHF propagation situations.

The text discusses first the general principles of free-space UHF radio-wave propagation and then considers the various phenomena which modify that simple state of affairs. Because of the finite average gradient with altitude of the refractive index of the atmosphere, electromagnetic waves tend to be bent toward the earth; this phenomenon is examined and the convenient and useful approximation of the 4/3-radius earth model is explained. The mechanism of multipath transmission, including the laws of reflection from a spherical earth surface of complex dielectric constant, is developed and applied to several examples which are then compared with experimental data. Utilizing methods described first by K. A. Norton, there is a discourse on surface-wave propagation of particular importance in the region beyond line of sight; results are given for different choices of frequency, polarization, and surface properties. The manner in which antenna and diversity

EDITOR'S NOTE: This issue of the Book Reviews section was edited by Dr. Irvin Glassman, Associate Editor of *JET PROPULSION*, during Dr. G. F. Warner's absence from his regular position at Purdue University. Dr. Warner will return to active editorship in October.

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transmitting and receiving arrangements alleviate the limitations imposed on a communications system by undesirable propagation effects is considered. The authors emphasize the communication link as a complete system in which the parameters of all of the components (including the propagation circuits) should be compatible. A chapter is included on nonstandard meteorological conditions illustrating "ducting" of UHF waves, a phenomenon of recent interest in UHF propagation studies.

The book is a reliable and authentic text for the not too sophisticated student of propagation and is an excellent reference work for a UHF communications-systems engineer.

Relativity and Reality, A Re-interpretation of Anomalies Appearing in the Theories of Relativity, by E. G. Barter, Philosophical Library, New York, N. Y., 1953, 131 pp. \$4.75.

Reviewed by M. D. KRUSKAL
Princeton University

The author pleads sincerely but unconvincingly for a return to absolute space and time and classical electromagnetic theory. He presents several supposed paradoxes in the theory of relativity, which are, however, easily resolved by anyone familiar with the fundamentals. In any case, those in the special theory would apply equally well to the classical electromagnetic theory which he accepts, although he of course denies this. Part of the confusion stems from the entirely non-mathematical nature of the treatment.

He also gives metaphysical arguments, in which his concepts of reality, mathematics, reasoning, etc., are peculiar and difficult to accept. His attitudes, particularly toward reality, with which he is much concerned, are the very antithesis of logical positivism.

Our Neighbour Worlds, V. A. Firsoff, Philosophical Library, New York, N. Y., 1953, 336 pp. \$6.

Reviewed by R. B. CANRIGHT
Douglas Aircraft Company

This book is basically an up-to-date review, in the semipopular vein, of planetary astronomy. Combined with the astronomy, however, are some chapters on space travel which are based on the thinking in the British Interplanetary Society. The spatial navigation presented is basically applied celestial mechanics. The reviewer believes that the inclusions of space travel and navigation tend to detract somewhat from the value of this book, at least for readers of JET PROPULSION. (For example, the author lightly compares navigational techniques for certain interplanetary journeys, saying that one type of trajectory requires "only" 5 mi/sec more velocity than another; 5 mi/sec is, of course, the satellite velocity for Terra!)

The astronomy was quite interesting. Separate chapters are given on the origin of the planets, Mercury, Venus, Luna, Mars, the outer planets, the satellites, and asteroids. The author does not hesitate to present his own views and generally makes it clear when his opinions are in

opposition to presently accepted astronomical thought. For example, he theorizes, rather convincingly, that the planets are the debris left after an early novalike solar explosion. He presents data and deductions to show that human existence on other planets (e.g., Mercury) would not be nearly so bleak and grim as has often been predicted.

Space Travel, K. W. Gatland and A. M. Kunesch, Philosophical Library, New York, N. Y., 1953, 205 pp. \$4.75.

Reviewed by R. B. CANRIGHT
Douglas Aircraft Company

In a strictly nonmathematical treatment, the authors, who are members of the British Interplanetary Society, discuss the past history of rockets and rocketry and the most probable (to them) future developments, which are presumed ultimately to culminate in interplanetary travel. Also included are brief discussions of the problems of man in space; communications, weightlessness, the space suit, high accelerations, temperature in space, etc.

The history of rocketry in Germany is covered quite completely. As an example of the coverage, the performance characteristics of the three-step, solid-propellant vehicle "Rheinbote" and of Dr. Sänger's intercontinental rocket bomber are presented, together with the customary V-1 and V-2 and rocket plane developments. The Viking firings (glossing over No. 8), the NACA research at Wallops Island, and the development of rocket-propelled research aircraft are included with Dr. Goddard's work and the Jet Propulsion Laboratory milestones to form America's contribution to the history of rocketry. However, inaccuracies were discovered in the presentation of the early history of GALCIT Project No. 1 (now Jet Propulsion Laboratory of California Institute of Technology), with which this reviewer is familiar; it is hoped that similar inaccuracies are not present in the other discussions of rocket history.

The remainder of the book is largely speculation, even though it must be admitted that the speculation is based on extrapolation of the best available (i.e., nonclassified) scientific data. This reviewer believes that not enough data are available to justify such a large extrapolation. On the other hand, the numerous plates are highly recommended; a wide range of subjects is presented in excellent reproductions.

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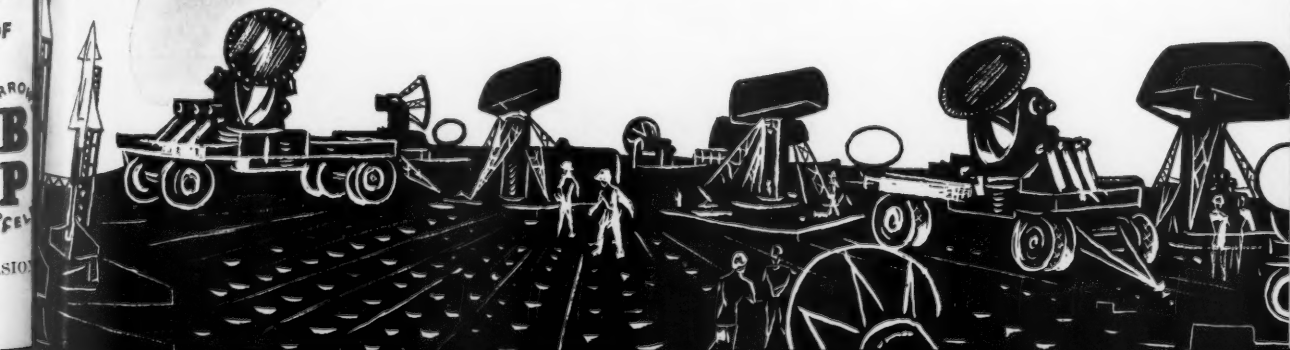
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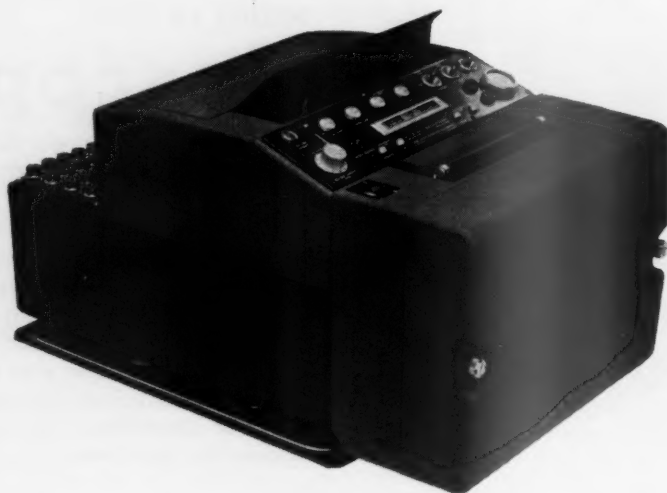
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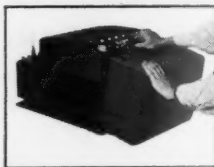
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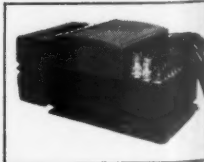
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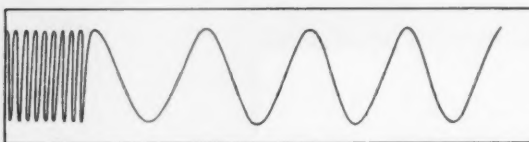
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Jet Propulsion Engines

Optimization of Power-Plant and Airplane Performance—a Symposium. *Aeronautical Engineering Review*, vol. 13, June 1954, pp. 42–56.

The Compound Aero Engine, by E. E. Chatterton, *Aeronautics*, vol. 30, June 1954, pp. 61–62, 67–68, 71.

Characteristics of a Vaporizing Combustor for Aviation Gas Turbines, by W. D. Pouchot and J. R. Hamm, *Trans. ASME*, vol. 76, July 1954, pp. 801–807.

Contribution to the Study of Axial Supersonic Compressors, by Pierre Schwaar, *ZAMP*, vol. 5, Mar. 15, 1954, pp. 136–15 (in French).

Applications of Dimensional Analysis to Spray-Nozzle Performance Data, by R. Shafer and Harry L. Bovey, *J. Res. Nat. Bur. Stand.*, vol. 52, March 1954, pp. 141–147.

Gas Turbine Starters for Jet Engines, by L. R. Neurlin and F. W. Fernald, *Aviation Age*, vol. 21, May 1954, pp. 138–146.

The Future of the Turbo Compound Engine, by Russell R. Mock and Norton B. Jamieson, *Mechanical Engineering*, vol. 76, May 1954, pp. 603–606.

Helicopter's Hopes Lifted by Turbo-prop, by Robert M. Loebelson, *Amer. Aviation*, vol. 18, July 5, 1954, pp. 15–16.

Anglo-American Jewel (Description of the Wright J-65 Sapphire), *Flight*, vol. 65, June 18, 1954, pp. 787–788.

Turbo-Wasp Dissected (Pratt and Whitney J-57), *Flight*, vol. 65, May 14, 1954, pp. 619–620.

Compression Ignition Gas Turbine (Napier Nomad), by C. D. Carmichael, *Shell Aviation News*, No. 192, June 1954, pp. 16–20.

Gas Turbines for Helicopters, by H. C. Maskey, *Continental Aviation and Engng. Corp.*, Feb. 1954, 17 pp.

Experiments on Model Thrust Reversers for Jet Aircraft, by M. A. Hiatt, *Boeing Aircraft Co. Document No. D-15077*, March 1954.

Preliminary Analysis of Problem of Determining Experimental Performance of Air-Cooled Turbine. I. Methods for Determining Heat Transfer Characteristics, by H. H. Ellerbrock and R. R. Ziemer. II. Methods for Determining Cooling-Air Flow Characteristics, by H. H. Ellerbrock. III. Methods for Determining Power and Efficiency, by H. H. Ellerbrock III, and R. R. Ziemer, *NACA RM E50A05*, and *E50A06*, Jan. 1950, and *E50E18*, May 1950. (Declassified 1953)

Effect of Air Distribution on Radial Temperature Distribution in One-Sixth Sector of Annular Turbojet Combustor, by Herman Mark and Eugene V. Zettle, *NACA RM E9L22*, Sept. 1949. (Declassified 1953)

Radiant Heat Transfer From Flames in a Single Tubular Turbojet Combustor, by Leonard Topper, *NACA RM E52F23*, June 1952. (Declassified 1953)

Comparison of Outside-Surface Heat-Transfer Coefficients For Cascades of Turbine Blades, by James E. Hubbard,

NACA RM E50C28, March 1950. (Declassified 1953)

Heat Transfer and Operating Characteristics of Aluminum Forced-Convection and Stainless-Steel Natural Convection Water-Cooled Single-Stage Turbines, by John C. Freche and A. J. Diaguila, *NACA RM E50D03a*, April 1950. (Declassified 1953)

Analytical Investigation of Flow and Heat Transfer in Coolant Passages of Free-Convection Liquid Cooled Turbines, by E. R. G. Eckert and Thomas W. Jackson, *NACA RM E50D25*, April 1950. (Declassified 1953)

Numerical Solution of Equations for One-Dimensional Gas Flow in Rotating Coolant Passages, by W. Byron Brown and Richard J. Rossbach, *NACA RM E50E04*, May 1950. (Declassified 1953)

Extension of Boundary Layer Heat Transfer Theory to Cooled Turbine Blades, by W. Byron Brown and Patrick L. Donoughe, *NACA RM E50F02*, June 1950. (Declassified 1953)

Analytical Determination of Local Surface Heat Transfer Coefficients For Cooled Turbine Blades From Measured Metal Temperatures, by W. Byron Brown and Jack B. Esgar, *NACA RM E50F09*, June 1950. (Declassified 1953)

Determination of Gas-to-Blade Convection Heat-Transfer Coefficients on a Forced Convection, Water Cooled Single-Stage Aluminum Turbine, by John C. Freche and Eugene F. Schum, *NACA RM E50J23*, Oct., 1950. (Declassified 1953)

Average Outside-Surface Heat-Transfer Coefficients and Velocity Distributions For Heated and Cooled Impulse Turbine Blades in Static Cascades, by James E. Hubbard and Eugene F. Schum, *NACA RM E50L20*, Dec. 1950. (Declassified 1953)

Determination of Blade to Coolant Heat Transfer Coefficients on a Forced Convection, Water-Cooled, Single-Stage Turbine, by John C. Freche and Eugene F. Schum, *NACA RM E51E18*, May 1951. (Declassified 1953)

Calculations of Laminar Heat Transfer Around Cylinders of Arbitrary Cross Section and Transpiration Cooled Walls With Application To Turbine Blade Cooling, by E. R. G. Eckert and John N. B. Livingood, *NACA RM E51F22*, June 1951. (Declassified 1953)

Blade to Coolant Heat Transfer Results and Operating Data From a Natural Convection Water Cooled Single-Stage Turbine, by Anthony J. Diaguila and John C. Freche, *NACA RM E51I17*, Sept. 1951. (Declassified 1953)

Experimental Investigation of Coolant-Flow Characteristics of a Sintered Porous Turbine Blade, by Edward R. Bartoo, Louis J. Schafer, Jr., and Hadley T. Richards, *NACA RM E51K02*, Nov. 1951. (Declassified 1953)

Experimental Investigation of the Heat-Transfer Characteristics of an Air-Cooled Sintered Porous Turbine Blade, by Louis J. Schafer, Jr., Edward R. Bartoo, and Hadley T. Richards, *NACA RM E51K08*, Nov. 1951. (Declassified 1953)

Pressure Drop in Coolant Passages of Two Air-Cooled Turbine Blade Configurations, by W. Byron Brown and Henry O. Slone, *NACA RM E52D01*, April 1952. (Declassified 1953)

Comparison of Calculated and Experimental Temperatures of Water-Cooled Turbine Blades, by Eugene F. Schum, John C. Freche, and William J. Stelpflug, *NACA RM E52D21*, April 1952. (Declassified 1953)

Analytical Investigation of Two Liquid Cooling Systems For Turbine Blades, by Thomas W. Jackson and John N. B. Livingood, *NACA RM E51F04*, June 1951. (Declassified 1953)

Experimental Investigation of Air-Cooled Turbine Blades in Turbojet Engine. X-Endurance Evaluation of Several Tube-Filled Rotor Blades, by Jack B. Esgar and John L. Clure, *NACA RM E52B13*, Feb. 1952. (Declassified 1953)

Rocket Propulsion Engines

Wheel Propulsion and Rocket Propulsion, by Eugen Sanger, *ZAMP*, vol. 5, Mar. 15, 1954, pp. 164–167 (in German).

A Review of the Current Techniques of Protecting and Cooling Rocket Motor Walls, by H. Ziehl, *J. Brit. Interplan. Soc.*, vol. 13, May 1954, pp. 129–141.

Heat Transfer and Fluid Flow

Convective Heat Transfer for Mixed, Free, and Forced Flow Through Tubes, by E. R. G. Eckert and A. J. Diaguila, *Trans. ASME*, vol. 76, May 1954, pp. 497–506.

Growth of a Vapor Bubble in a Superheated Liquid, by H. K. Forster and N. Zuber, *J. Appl. Phys.*, vol. 25, April 1954, pp. 474–478.

Growth of Vapor Bubbles in Superheated Liquids, by M. S. Plesset and S. A. Zwick, *J. Appl. Phys.*, vol. 25, April 1954, pp. 493–500.

Cascade Flow Investigations, by Norbert Scholz, *VDI-Forschungsheft* 442, 1954, 48 pp. (in German).

Study of the Influence of Tube Diameter on the Velocity of Explosive Waves, *Rev. Inst. Français Pétrole et Ann. Comb. Liquides*, vol. 9, May 1954, pp. 216–219 (in French).

Determining Skin Friction Temperature, by William D. Murray and Lawrence Slot, *Aero Digest*, vol. 68, June 1954, pp. 33–36, 38, 42.

Some NACA Research on Centrifugal Compressors, by J. A. Johnsen and Ambrose Qinsburg, *Trans. ASME*, vol. 75, July 1954, pp. 805–817.

A Practical Solution of a Three-dimensional Flow Problem of Axial-Flow Turbomachinery, by L. H. Smith, Jr., S. C. Traugott, and G. F. Wislicenus, *Trans. ASME*, vol. 75, July 1954, pp. 789–803.

An Experimental and Theoretical Investigation of Two-Dimensional Centrifugal-Pump Propellers, by A. J. Acosta, *Trans. ASME*, vol. 76, July 1954, pp. 749–763.

EDITOR'S NOTE: This collection of references is not intended to be comprehensive, but is rather a selection of the most significant and stimulating papers which have come to the attention of the contributors. The readers will understand that a considerable body of literature is unavailable because of security restrictions. We invite contributions to this department of references which have not come to our attention, as well as comment on how the department may better serve its function of providing leads to the jet propulsion applications of many diverse fields of knowledge.

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Fluid Dynamics (Review of the Literature), by A. J. Oppenheim and Thomas Baron, *Ind. Engng. Chem.*, vol. 46, May 1954, pp. 938-947.

Heat Transfer (Review of the Literature), by E. R. G. Eckert, *Ind. Engng. Chem.*, vol. 46, May 1954, pp. 932-937.

Formation and Velocity of Spherical Explosion Waves of Gaseous Mixtures, by N. Mausou (in French). *Revue de l'Institut Français du Pétrole*, vol. 9, April 1954, pp. 133-143.

Report on the Flow Phenomena at Supersonic Speed in the Neighborhood of the Entry of a Propulsive Duct, by G. H. Lean, *Gi. Brit. Aeron. Res. Council. Reps. and Memo.* no. 2827, 1954, 15 pp.

Analysis of Turbulent Heat Transfer, Mass Transfer, and Friction in Smooth Tubes at High Prandtl and Schmidt Numbers, by Robert G. Deissler, *NACA Technical Note*, May 1954, 53 pp.

Preliminary Measurements of Turbulence and Temperature Fluctuations Behind a Heated Grid, by A. L. Kistler, V. O'Brien, and S. Corrin, *NACA RM No. 54D19*, June 1954, 24 pp.

Viscosity of Suspensions. Review and Application to Two Phase Flow, by Thomas Baron, C. S. Sterling, and A. P. Schueler, *Midwest. Conf. Fluid Mechanics, 3rd Proceedings*, 1953, pp. 103-128.

Review of Transport Processes in Turbulent Shear Flows, by Arnold M. Kuethe, *Midwest. Conf. Fluid Mechanics, 3rd Proceedings*, 1953, pp. 85-101.

Experimental Investigation of Free-Convection Heat Transfer in Vertical Tube at Large Grashof Numbers, by E. R. G. Eckert and A. J. Diaguila, *NACA RM E52F30*, June 1952. (Declassified 1953)

Collision Kinetics in a Shock Wave, by T. P. Cotter, *Atomic Energy Commission, Los Alamos Scientific Laboratory*, LA-1413, March 1952, 17 pp.

The Influence of Electric Fields on Heat Transfer in Gases (in German), by H. Senftleben, and E. Bultmann, *Zeit. für Physik*, vol. 136, no. 4, 1953, pp. 389-401.

Mathematical Theory of the Flow of a Gas in a Porous Solid and of the Associated Temperature Distributions, by D. R. Bland, *Proc. Roy. Soc.*, vol. A221, Jan. 7, 1954, pp. 1-28.

Mass Transfer in Laminar Flow, by D. B. Spalding, *Proc. Roy. Soc.*, vol. A221, Jan. 7, 1954, pp. 78-99.

Mass Transfer From a Laminar Stream to a Flat Plate, by D. B. Spalding, *Proc. Roy. Soc.*, vol. A221, Jan. 7, 1954, pp. 100-104.

Combustion

Vortex Burner, A Useful Tool for Studying the Flame Stability of Gaseous Fuels and Fuel Mixtures, by Philip F. Kurz, *Rev. Sci. Instrum.*, vol. 25, May 1954, pp. 418-421.

Flame Studies with a Vortex Burner, by Philip Kurz, *Ind. Engng. Chem.*, vol. 46, June 1954, pp. 1311-1316.

Flame Turbulence Measurements by the Method of Helium Diffusion, by Arthur A. Westenburg, *J. Chem. Phys.*, vol. 22, May 1954, pp. 816-823.

Interface Extension Versus Upper Limiting Time Mean Energy Release Rates of Constant Pressure Steady State Combustion Process, by W. J. Wohlenberg, *Trans. ASME*, vol. 76, May 1954, pp. 679-688.

Theory of Laminar Flame Stability, by J. B. Rosen, *J. Chem. Phys.*, vol. 22, April 1954, pp. 733-348.

Importance of Flame Configuration in Stability Experiments, by P. F. Kurz, *Fuel*, v. 33, July 1954, pp. 291-294.

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Flames, by D. B. Spalding, *Fuel*, v. 33, July 1954, pp. 255-273.

Comparison of the Spectra of Turbulent and Laminar Flames, by A. G. Gaydon and H. G. Wolfhard, *Fuel*, v. 33, July 1954, pp. 286-290.

Determination of the Distribution of Some Parameters Across the Combustion Zone of a Flat Flame, by J. H. Burgoyne and F. J. Weinberg, *Proc. Roy. Soc.*, vol. A 224, July 7, 1954, pp. 286-308.

Ignition Studies. Part III. Ignition Properties of the Isomeric Hexanes, by Enoch Johnson, John W. Crellin, and Homer W. Carhart, *Naval Res. Lab. Rep.* no. 3446, April 1954, 18 pp.

An Experimental Study of the Characteristics of High Speed Turbulent Flames in Premixed Gases, by Sydney H. Reiter, *Princeton Univ. Dept. Aeron. Engng. Rept.* no. 259, May 1954, 96 pp.

Mechanism of Burning of Nitrate Esters, by Rudolph Steinberger and Kenneth E. Gardner, *Hercules Powder Co., Allegany Ballistics Lab.*, April 1954, 9 pp.

The Thermodynamics of Combustion Gases: Temperature of Acetylene Air Flames, by R. W. Smith, Jr., John Manton, and S. R. Brinkley, Jr., *Bur. Mines. Rept. Investigations No. 5035 (Project Squid Rept. No. BUM-10R)*, Feb. 1954, 14 pp.

Flame Quenching by a Variable-Width Rectangular-Slot Burner As a Function of Pressure for Various Propane-Oxygen-Nitrogen Mixtures, by Abraham L. Berladi, *NACA RM E53K30*, Jan. 1954, 42 pp.

High-Speed Photography of Spark Ignited, Low Pressure Explosions of Hydrogen Oxygen and Methane-Oxygen Mixtures, by A. J. Everett and G. J. Minkoff, *Fuel*, vol. 33, Jan. 1954, pp. 66-78.

An Evaluation of the Soap Bubble Method for Burning Velocity Measurements Using Ethylene-Oxygen-Nitrogen and Methane-Oxygen-Nitrogen Mixture, by Dorothy M. Simon and Edgar L. Wong, *NACA TN 3106*, Feb. 1954, 30 pp.

Comments on the Thermal Decomposition of Ozone, by P. Harteck and S. Dondes, *J. Chem. Phys.*, vol. 21, Dec. 1953, pp. 2241.

The Decomposition of Ozone on the Surface of Glass Wool, by P. Harteck and S. Dondes, *J. Chem. Phys.*, vol. 21, Dec. 1953, pp. 2240-2241.

Theory of Laminar Flame Stability. I. Analytical Stability Condition, by J. B. Rosen, *J. Chem. Phys.*, vol. 22, April 1954, pp. 733-742.

Theory of Laminar Flame Stability. II. General Numerical Method and Application to Typical System, by J. B. Rosen, *J. Chem. Phys.*, vol. 22, April 1954, pp. 743-748.

Combustion Wave Stability and Flammability Limits, by J. B. Rosen, *J. Chem. Phys.*, vol. 22, April 1954, pp. 750-751.

Selective Combustion in Propane-Diborane Flames, by P. F. Kurz, *Fuel*, vol. 33, April 1954, pp. 250-251.

Effect of Vaporization Rate on the Weak Combustion Limit of Liquid Fuel Sprays, by J. Whittle, *Fuel*, vol. 33, April 1954, pp. 192-194.

Self Acceleration of Spark Ignited Explosions in Narrow Tubes, by A. J. Everett and G. J. Minkoff, *Fuel*, vol. 33, April 1954, pp. 184-191.

Flame Propagation in the Self Combustion of Acetylene, by W. E. Prout and R. C. Anderson, *Fuel*, vol. 33, April 1954, pp. 125-133.

An Oscillographic Method for Determining Velocities of Detonation in Explosives, by Frank C. Gibson, *Rev. Sci. Instrum.*, vol. 25, March 1954, pp. 226-231.

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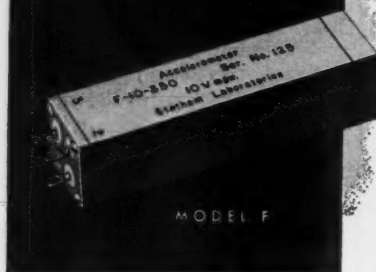
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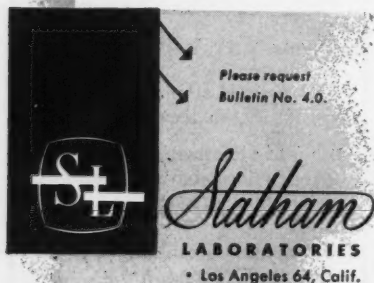
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Fuels, Propellants, and Materials

Combustion of Gaseous Hydrazine, by Peter Gray and J. C. Lee, *Trans. Faraday Soc.*, vol. 50, Pt. 7, July 1954, pp. 719-728.

Propellants for Rockets and Space Ships, by Johan G. Tschinkel, *Chem. and Engng. News*, vol. 32, June 28, 1954, pp. 2583-2587.

Solid Ozone, by Cellaway Brown, Abraham Berger, and Charles K. Hersh, *J. Chem Phys.*, vol. 22, June 1954, pp. 1151-1152.

Ceramics for Aircraft Propulsion Systems, by Lloyd D. Richardson, *Bull. Amer. Ceramic Soc.*, vol. 33, May 1954, pp. 135-137.

Thermal Expansion of Extruded, Solventless, Double-Base Propellants, by Ralph M. Moon, Jr., *NAVORD Rep.* 2083 (NOTS 819), Jan. 1954, 42 pp.

Viscosity and Density of the Nitric-Acid-Nitrogen Dioxide-Water System, by David M. Mason, Ira Petker, and Stephen P. Vango, *Calif. Inst. Tech. Jet Prop. Lab. Prog. Rep.* no. 20-214, Jan. 1954, 33 pp.

Simple Rapid, Infrared Method for the Determination of Nitroglycerin, Triacetin, and 2-Nitrodiophenylamine in Casting Propellants, by A. H. Castelli, M. Halik, W. E. Frederick, and F. Pristera, *Picatinny Arsenal Tech. Rep.* no. 2021, April 1954, 9 pp.

Applicability of Time Temperature Superposition Principle to Cellulose Nitrate, by Elise McAbee, *Picatinny Arsenal, Techn. Rep.* no. 2072, May 1954, 10 pp.

Analysis of Double Base Propellants by Infrared Spectroscopy, by R. W. Philips and Rudolph Steinberger, *Hercules Powder*

Co., Allegany Ballistics Lab. Rep. no. ABL/P-23, Jan. 1954, 14 pp.

Carbon Deposition Characteristics of MIL-F-5624A Fuels Containing High Boiling Aromatic Hydrocarbons, by Edwund R. Jonash, Jerrold D. Wear, and Juilliam P. Cook, *NACA RM E52G11*, mly 1952. (Declassified 1953)

Preliminary Investigation of Zirconium Boride Ceramals For Gas-Turbine Blade Applications, by Charles A. Hoffman, *NACA RM E52L15a*, Dec. 1952. (Declassified 1953)

Fuel Characteristics Pertinent to the Design of Aircraft Fuel Systems; Supplement 1—Additional Information on MIL-F-7914 (AER) Grade JP-5 Fuel and Several Fuel Oils, by Henry C. Barnett and Robert R. Hibbard *NACA RM E53I16*, Sept. 1953. (Declassified 1953)

Fuel Characteristics Pertinent to the Design of Aircraft Fuel Systems, by Henry C. Barnett and R. R. Hibbard, *NACA RM E53A21*, Jan. 1953. (Declassified 1953)

Analytical Investigation of Fuel Temperatures and Fuel Evaporation Losses Encountered in Long Range High Altitude Supersonic Flight, by Richard J. McCafferty, *NACA RM E53E25*, May 1953. (Declassified 1953)

Preliminary Investigation of Effects of Alpha-Particle Bombardment on the Creep Rate of Aluminum, by J. Howard Kittel, *NACA RM E7E13*, May 1947. (Declassified 1953)

Properties of Low-Carbon N-155 Alloy Bar Stock From 1200° to 1800° F., by J. W. Freeman and A. E. White, *NACA RM 51B05*, Feb. 1951. (Declassified 1953)

Investigation of Titanium Carbide Base Ceramals Containing Either Nickel or Cobalt For Use as Gas-Turbine Blades,

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by C. A. Hoffman and A. L. Copper, NACA RM E52H05, Aug. 1952. (Declassified 1953)

Effect of Magnitude of Vibratory Load Superimposed on Mean Tensile Load on Mechanics of and Time to Fracture of Specimens and Correlation to Engine Blade, by Robert R. Ferguson, NACA RM E52I17, Sept. 1952. (Declassified 1953)

Short-Time High Temperature Properties of Heat-Resisting Alloy Sheet, by W. F. Simmons, J. A. Van Echo and H. C. Cross, *Rand Corp. Report R-147*, June 1949. (Declassified 1953)

Short-Time, High-Temperature Properties of Heat Resisting Alloy Sheet, by H. C. Cross, R. C. McMaster, W. F. Simmons, and J. A. Van Echo, *Rand Corp. Report RA-15077*, Feb. 27, 1948. (Declassified 1953)

Physical-Chemical Topics

Approximate Emissivity Calculations for Polyatomic Molecules. Part I, CO₂, by S. S. Penner, *J. Appl. Phys.*, vol. 25, May 1954, pp. 660-667.

A Review of Thermal Radiation Constants, by N. W. Snyder, *Trans. ASME*, vol. 76, May 1954, pp. 537-539.

Thermal Conductivity of Gases, by F. G. Keyes, *Trans. ASME*, vol. 76, July 1954, pp. 809-816.

Thermodynamics of Irreversible Processes and Their Application to Transport Phenomena, Part II, by H. Y. Reik (in German), vol. 137, No. 4, May 8, 1954, pp. 463-492.

Kinetics of Thermal Decomposition of Ammonium Nitrate, by Bernard J. Wood and Henry Wise, *Calif. Inst. Tech. Jet Pro. Lab. Prog. Rep.* no. 20-215, Jan. 1954. 17 pp.

Exchange Between Rotational and

Translational Energy in Gas Molecules, by John C. Beckerle, *J. Chem. Phys.*, vol. 21, Nov. 1953, pp. 2034-2041.

Instrumentation and Experimental Techniques

A Fast-Response True-Mass-Rate Flowmeter, by Yao Tzu Li and Shih-Ying Lee, *Trans. ASME*, vol. 75, July 1954, pp. 835-841.

Stabilized Noise Source for Air-Weapons Design, by D. E. Beecher, R. K. Bennett, and H. Low, *Electronics*, vol. 27, July 1954, pp. 163-165.

A New Radiometer, by J. T. Houghton and A. W. Brewer, *J. Sci. Instrum.*, vol. 31, May 1954, pp. 184-187.

Method for Rapid Determination of Pressure Change for One-Dimensional Flow with Heat Transfer, Friction, Rotation and Area Change, by James E. Hubbard, Henry O. Stone, and Veron L. Arne, *NACA TN* no. 3150, June 1954, 22 pp.

Measurement of the Conductivity of a Jet Flame, by Fred P. Alder, *J. Appl. Phys.*, vol. 25, July 1954, pp. 903-906.

Electron Shadowgraphs and Afterglow Pictures of Gas Jets at Low Densities, by A. E. Grun, E. Schopper, and B. Schumacher, *J. Appl. Phys.*, vol. 24, Dec. 1953, pp. 1527-1528.

Terrestrial Flight, Vehicle Design, etc.

Aeronautical Acoustics, In Particular Jet Noise (A Symposium), *J. Roy. Aeron. Soc.*, vol. 58, April 1954, pp. 221-260.

The Experimental Determination of Guided Missile Reliability, by M. R. Sheldon and D. W. Pertschuk, *J. Opera-*

tions Res. Soc. of America, vol. 2, Feb. 1954, pp. 31-40.

Progress Toward Astronautics, by Kenneth W. Gatland, *J. Brit. Interplan. Soc.*, vol. 13, May 1954, pp. 142-166.

Space Flight

Navigation Problems in Space Flight. IV. The Aspects of Atmospheric Friction (The Earth's Atmosphere), by Harold B. Ketchum, *J. Space Flight*, vol. 6, June 1954, pp. 1-8.

Development of a Lunar Base, by G. E. V. Awdry, *J. Brit. Interplan. Soc.*, vol. 13, May 1954, pp. 166-169.

Effect of Tidal Friction on a Near Satellite, by J. Logie, *J. Brit. Interplan. Soc.*, vol. 13, May 1954, pp. 170-175.

Astrophysics, Aerophysics, Atomic Physics

Systematic Wind Measurements at Altitudes of 80-100 km Using Radio Echoes from Meteor Trails, by J. S. Greenhow, *Phil. Mag.*, vol. 47, no. 364, May 1954, pp. 471-490.

Coupled Forms of the Differential Equations Governing Radio Propagation in the Ionosphere, by P. C. Clemmow and J. Heading, *Proc. Cam. Phil. Soc.*, vol. 50, part 2, April 1954, pp. 319-333.

Contribution to the Study of Infrared Penetration of the Lower Atmosphere, by P. Barchewitz, G. Amat, and C. Rossetti (in French), *France. Min. de l'Air. Pub. Sci. et Tech.*, No. 116, Feb. 1954, 99 pp.

Absorption Coefficients of Several Atmospheric Gases, by K. Watanabe, Murray Zelikoff, and Edward C. Y. Inn, *A. F. Cambridge Res. Center. Tech. Rep.* no. 53-23 (*Geophys. Res. Papers* no. 21), June 1953, 79 pp.

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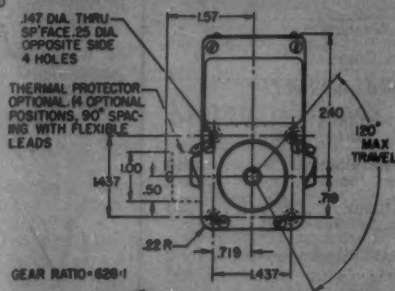
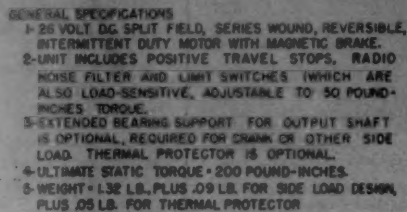


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